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FINAL REPORT

WASTE COLLECTION SUBSYSTEM STUDY

CONTRACT NAS 9-17183

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TX 77058

BY

HAMILTON STANDARD

DIVISION OF UNITED TECHNOLOGIES CORPORATION

WINDSOR LOCKS, CT 06096

DECEMBER 1984

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ABSTRACT

This report describes the design concept definition studies for an improved Space Shuttle waste collection subsystem conducted to improve waste compaction and rapid turnaround, with possibilities for application to Space Station. These concepts were developed under contract NAS 9-17183, Waste Collection Subsystem Study and were presented to NASA/JSC on November 1, 1984.



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FOREWORD

This report has been prepared by Hamilton Standard, a division of United Technologies Corporation for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center in accordance with the requirements of contract NAS 9-17183, Design Concept Definition Study for an Improved Shuttle Waste Collection Subsystem.

Personnel responsible for the conduct of this study were Mr. H.F. Brose, Program Manager, and Mr. D.C. Jennings, Project Engineering Manager. Appreciation is expressed to Mr. T.A. Lewis, Design Engineer of Hamilton Standard and Mr. H.E. Winkler, Technical Monitor for NASA/JSC. Appreciation is also expressed to Messrs. A.M. Boehm, A.K. Davenport, A.A. Decrisantis, C.W. Flugel, G.N. Kleiner, Dr. G.P. Noyes, E.W. O'Connor, G.J. Roebelen, Jr., and J.E. Swider who formed the Hamilton Standard Review Team for their valuable contributions.

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1.0 SUMMARY

This study program explored practical ways of improving waste compaction and of providing rapid turnaround between flights at essentially no cost for the Space Shuttle waste collection subsystem commode. Because of the possible application of a fully developed Shuttle commode to the Space Station, means of providing waste treatment without overboard venting were also considered.

Three basic schemes for compaction and rapid turnaround, each fully capable of meeting the objectives, were explored in sufficient depth to bring out the characteristic advantages and disadvantages of each. Tradeoff comparisons were very close between leading contenders and efforts were made to refine the design concepts sufficiently to justify a selection. The concept selected makes use of a sealed canister containing wastes that have been forcibly compacted, which is removable in flight.

No selection was made between three superior non-venting treatment methods owing to the need for experimental evaluations of the processes involved.

A system requirements definition document has been prepared to define the task for a test embodiment of the selected concept.

A set of four, half-scale drawings has been included with this report. These drawings, SVSK 109313, SVSK 111101, SVSK 111104 and SVSK 111105 supplement the report which has the major views of each included among the illustrations.

2.0 INTRODUCTION

Space Shuttle orbiter waste collection subsystem problems on flights STS-1 through STS-9 follow a pattern of steady improvement as the result of corrective actions taken between flights. A major problem, that of ejection of waste matter from the commode, was under attack at the outset of the present study. A rotating slinger within the commode had been removed, and a filter bag within the commode was awaiting demonstration as a satisfactory means of capturing and retaining wastes entrained by an inward airflow. On flights STS-41D and STS-41G the modified commode performed in a fully satisfactory manner. There remained two important problems which could not be addressed by minor changes to the commode between flights. These were the compaction of wastes to obtain an extended mission duration capacity and a means of providing rapid turnaround between flights involving essentially no cost. Furthermore the possibility of eventual application of an improved Shuttle commode to the Space Station was of interest. The present study was undertaken to devise design concepts capable of meeting these three objectives, and to make possible the selection of an optimum concept by NASA.

During the course of this study Hamilton Standard arrived at a viewpoint from which these objectives could be attained by a turnaround capability while in flight, taking about 5 minutes effort by one crew member. On that basis the wastes compacted in the commode could be stored outside of the commode, and mission duration could thereby be extended indefinitely. It made rapid turnaround on the ground a matter of 5 minutes effort to empty the commode, and any wastes stored elsewhere would be removed without further involvement of the commode. Such a capability would lend itself to the long duration requirements of the Space Station. A requirement of the Space Station to avoid overboard venting generated additional considerations of waste treatment, differing from Space Shuttle practice. Hamilton Standard regarded drying, refrigeration and biodegradation to be acceptable alternatives to overboard venting of wastes. In this way the degree of compaction attained remained dependent upon an actual concept embodiment, but neither mission duration nor rapidity of turnaround would be dependent upon it.

The waste collection subsystem study was a three month, fixed price effort of a scope outlined in Figure 1. Work statement requirements are listed in Figure 2. Here can be seen the overall needs of a Space Shuttle waste collection subsystem and in particular the objectives already defined. Since the existing subsystem is fully capable, as demonstrated by flight experience, of performing satisfactorily, no changes should be made in those features which could deteriorate from change. Thus the crew member positioning and retention, the feces entrainment, airflow and dimensions of the seat, air jets, slide valve and transport tube diameter should not be changed. These have been retained identically in the Hamilton Standard design concepts, so that no loss in performance results.

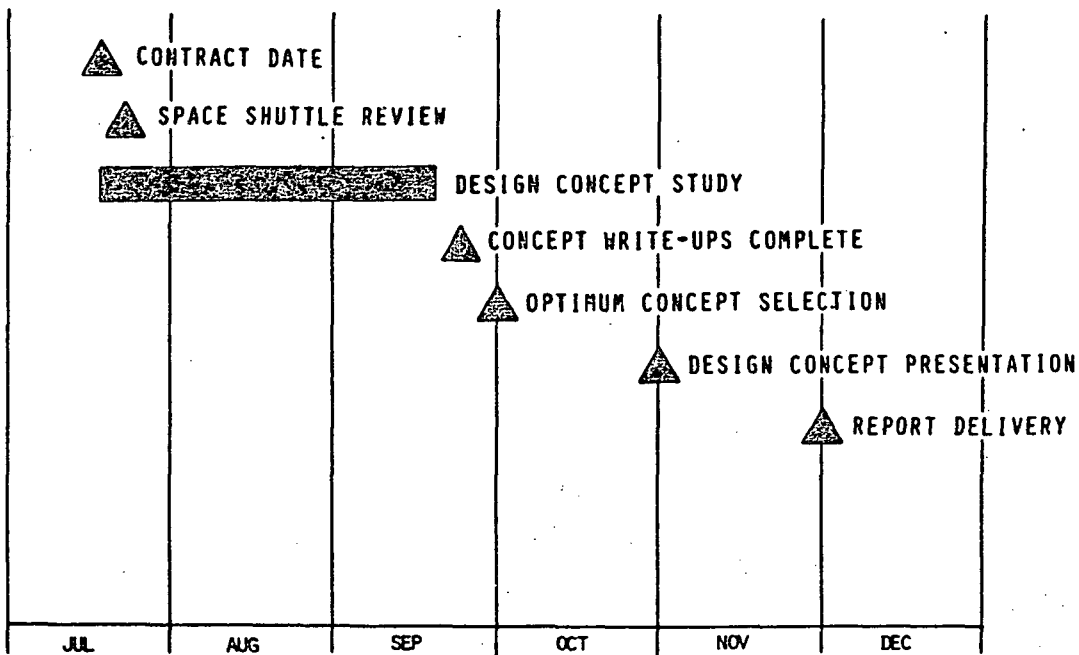


Figure 1
WASTE COLLECTION SUBSYSTEM STUDY



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General Requirements

- (1) Effectively and hygienically separate wastes from the crew member.
- (2) Store the wastes in a safe, odorless form separate from the crew compartment.

Specific Requirements

- (1) Accommodate use by both males and females.
- (2) Urine collection interface should be individual.
- (3) Be straightforward and simple in use and not take excessive time.
- (4) Capacity should not be limited by paper; i.e., separate paper compartment or compaction for papers and/or feces.
- (5) Require only minimal training for successful crew use.
- (6) Provide no handling of wastes by the crew.
- (7) Provide proper stool separation during use.
- (8) Provide adequate body stabilization for use.
- (9) Provide positive collection and retention of wastes and paper for a minimum of 210 man-days of use.
- (10) Include provisions for bacteria and odor control.
- (11) Be quiet during operation; not disturb sleep (goal: Noise Criteria (NC) 40).
- (12) Be maintainable at the launch site; require minimal turnaround time/impacts (goal: In-vehicle ground maintenance).
- (13) Minimize expendables, weight, power, and volume without compromising subsystem operational characteristics.
- (14) Be reliable and should include redundant electrical components and dual seals where practical.
- (15) Be retrofittable within current system compartment into the Orbiter fleet in the field; i.e., KSC.

Figure 2
WORK STATEMENT REQUIREMENTS

Collection and storage of fecal wastes and paper must be performed in a sanitary and odorless manner, requiring no manual handling of wastes in use, and preferably none at ultimate disposal. Sanitary collection and storage is assured if all bacteria are contained. Positive containment is a necessity whatever treatment means are imposed short of absolute sterilization, because treated bacteria still live. Containment in the Space Shuttle waste collection subsystem is by means of seals, inward airflow and filters. These means are quite basic in scope and are quite effective in practice, and are retained as operating principles in the new concepts resulting from this study. Odorless collection and storage are similarly assured by containment. Again, containment of odors is provided in the Space Shuttle by means of seals, inward airflow and filters, the same as for the containment of bacteria. The only difference is in the filter, and a suitable design can have both bacteria retaining and odor retaining features. Avoidance of handling necessitates mechanization of separation of feces and paper from the crew member, and of collection and containment of wastes. These features have been developed for the flight-proven Shuttle waste collection subsystem, and make use of air entrainment to convey the feces and paper away from the crew member and into the interior of the commode. There they are collected by means of a filter medium that stops the motion of the wastes, but passes the airflow onward to the fan separator and to the odor and bacteria filter. These features must be retained. New features are needed to compact the wastes including paper, and to store compacted wastes. Of primary emphasis, new features are needed to provide for rapid turnaround within the Space Shuttle vehicle.

An approach has been taken in this study to compact wastes, if possible for a concept, to obtain a capacity for 52.5 man-days accumulation, and to store wastes outside the commode in excess of that amount for the maximum 210 man-day mission. These wastes would be stored in the vehicle waste compartment to be provided for a mission of that extension. Where feasible, consideration has been given to a nominal mission capacity of at least 70 man-days. The design plan in transferring wastes in flight is to manually transfer clean packages of waste from a clean commode interior to a clean waste receptacle. Such a waste receptacle is assumed to be vented at a very low flow rate overboard on the Shuttle or to the odor and bacteria filter on the Space Station. In at least one configuration such a waste receptacle has been included within the original Shuttle commode space envelope.

During the course of this study several workable concepts were identified among the dozen or so considered. Each of the workable concepts displayed both attractive features and design difficulties. As efforts were concentrated on a specific difficulty a concept became more advanced, demanding that further attention be placed upon its competitors. In this way all the prominent conceptual difficulties associated with each of the contending concepts were worked out. That provided a sound basis for the ensuing tradeoff comparison.

The following concepts have been evaluated for selection as an improved waste collection subsystem for the Space Shuttle: (1) front door commode with three-layer bag, (2) a canister commode in three basic variations, and (3) the advancing sleeve commode.



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As a result of responses to the final presentation at NASA/JSC on November 1, 1984 further consideration was given to the stationary cansiter concept to point out routes that may be followed to advance from conceptual status to that of a design that may be worthy of experimental testing.

For possible application to Space Station nonventing treatment, three additional concepts have been evaluated, each of which can be based upon any one of the Space Shuttle commode concepts. These are (1) microwave drying (2) thermoelectric refrigeration, and (3) biodegradation. Selection was not made of an optimum treatment method because of the need to conduct experiments to refine the data upon which selection can be based.

3.0 CONCLUSIONS

The results of conducting a study on the Space Shuttle waste collection subsystem aimed at the improvement of waste compaction, rapid low cost turn-around, and the potential for non-venting application to the Space Station have produced the following conclusions:

- Rapid turn-around in flight permits rapid turn-around on the ground, and also permits indefinite mission extension by storing wastes outside the commode.
- Rapid turn-around in flight is essentially cost-free, except for the relatively low cost of containers produced in quantity.
- Principles of sanitation and odor control maintained by containment, making use of seals, inward airflow and filters, on the Space Shuttle should not be abrogated.
- Principles of mechanized waste separation developed and flight proven on the Space Shuttle, including crew member positioning, seat, air jets, slide valve, transport tube diameter, and airflow, should not be abrogated.
- Three basic means of waste collection and compaction have been identified as practical; namely, (1) filter bag collection with compaction by fan suction, (2) canister collection with compaction by force applied to compaction cups or disks, and (3) sleeve collection with compaction by rollers and winding on a reel.
- Canister collection and compaction ranks higher in crew acceptability than bag collection and compaction, and higher in reliability than sleeve collection and compaction, and is thereby preferable.
- Stationary disk canister collection and compaction ranks higher in compaction and in ease of operation than the cup canister configurations and is thereby superior.
- Non-venting waste treatment by microwave drying, thermoelectric refrigeration, and biodegradation are acceptable methods of waste treatment for storage, and require experimental testing to obtain data for proper selection.
- Destructive re-entry, making use of low velocity jettison, is worthy of study as a desirable alternative to compacted waste storage for Space Station.

4.0 RECOMMENDATIONS

Several recommendations are appropriate to the application of the results of this study to an improved Shuttle waste collection subsystem.

- A stationary canister commode using compaction disks should be designed as preliminary flight hardware to work out commode packaging details, canister fabrication details, and material selections.
- A test facsimile incorporating a simulated commode with realistic canister and compaction disks from the preliminary design should be fabricated and tested on the ground to demonstrate and improve compaction and canister removal procedures.
- A flight test canister based on the improved ground test configuration should be designed to fit within the existing Shuttle commode for actual flight demonstration.
- Flight hardware should then be designed based on the use of test results to improve the preliminary design.
- A program of testing microwave drying, refrigeration, and biodegradation of fecal wastes should be commenced to obtain design data on the effects of parameters such as weights, temperatures, pressures, flows, durations, and geometrical factors upon the gaseous products and odors produced, including their identifications and quantities.
- An evaluation of the advantages and disadvantages of destructive reentry as a means of limiting waste storage penalties should be undertaken.

5.0 DISCUSSION

The results of this study, concept definition of an improved Shuttle waste collection subsystem, is divided into two main parts. The first covers concepts for waste compaction and rapid turn-around. Three concepts are discussed separately and a trade-off comparison is made of them. The second part covers three concepts for non-venting waste treatment that would improve the applicability of an improved Shuttle waste collection subsystem to the Space Station. Although a trade-off comparison is made, no selection is defined for lack of sufficient experimental test data.

5.1 Concepts for Waste Compaction and Rapid Ground Turn-Around

Three concepts are to be discussed as follows: (1) A front door commode with bag collection using a three-layer bag which permits compaction of wastes by bag collapse from fan suction and easy disposal by plugging the bag neck, while access is through the front door; (2) canister collection using disposable cups or compaction disks placed in disposable canisters in which wastes are compacted with a plunger forced against the cups or disks separating the waste deposits, while canisters are revolved away, or are extracted for separate storage within the commode space envelope or other disposal; and (3) sleeve collection using a permeable sleeve unfolded by winding on a reel, and compacting wastes by drawing between rollers and winding tightly on the reel, with easy access to the loaded reel for disposal upon opening the commode.

5.1.1 Front Door Commode

A simple design concept, Figure 3, has been devised for a modification of the existing Space Shuttle commode that will provide quick turn-around between flights, and will compact the wastes for longer flights. A large front door has been cut into the pressure vessel which is easily reached through a permanent opening made in the plastic cover at the front. It will be a pressure assisted closure having a hinge at one side and a spring-loaded cam latch at the other. Fan suction will tend to close a lip type seal around the door during use, and vacuum venting will draw down the seal even more tightly. In this way, the need for multiple latches or a bolt circle is avoided. Loss of cabin pressure remains insured against by the vacuum vent line restriction already incorporated. Any leakage through the front door seal could be easily identified by closing the vacuum vent valve and watching for cabin nitrogen flow changes. Door hinge and latch mechanisms are strong enough to support the fittings for the user's tie down straps and the urinal attachment. Hand holds will be attached to the door and will be moved slightly forward to provide clearance for opening the door. The door continues the contour of the pressure vessel and the opening is torsionally stiffened by the sealing flanges, enabling the sealing surfaces to be minimally distorted by pressure changes. Furthermore, the door hinge has a large clearance hinge pin, spring-loaded to force the door against the jamb. In this way, with both latch and hinge applying spring force to the door, a metal-to-metal contact is obtained all the way around its perimeter insuring a controlled fit between the two surfaces contacted by the lip seal. Although leaving the door exposed is more convenient, and can be decorously painted, a plastic shield to match the contours of the original configuration could easily be attached to the commode door, leaving suitable clearance for the motion of the door.

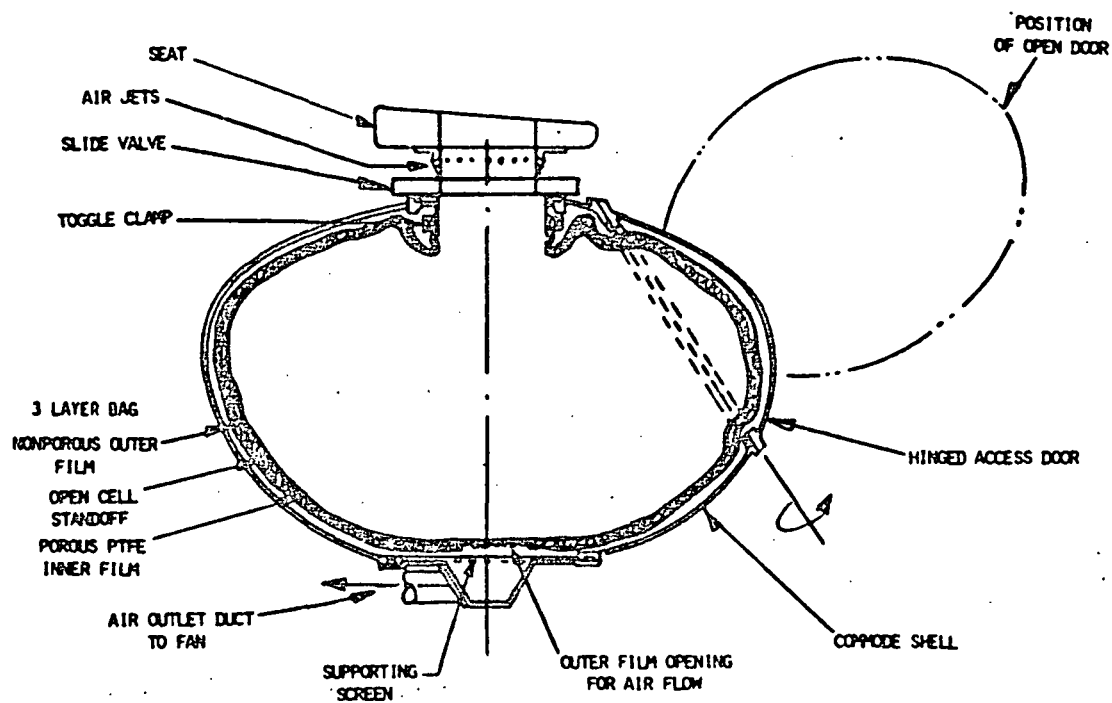


Figure 3
FRONT DOOR COMMODORE



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After a Space Shuttle flight, the commode is emptied and made ready for use on the next flight without dismantling or removing any equipment. First the slide valve is opened starting the fan separator, and a hollow plastic plug is inserted through the transport tube into the neck of the bag, snapping into the slide valve recess for positioning. Then, the front door of the commode is unlatched and swung to the side on its hinge, exposing the clean outer surface of an impervious plastic film covering the three-layer bag within. Upon opening the door, suction from the fan separator exhausts the air from the bag collapsing it around its contents and thereby compacting them. Meanwhile, the odorous air that might otherwise escape is sent through the odor and bacteria filter downstream of the fan separator. When fully compacted, a hand is reached inside the commode, contacting only clean surfaces within, and engages a toggle clamp around the plug. A similar clamp holding the neck of the bag around the bottom of the transport tube is released, and the collapsed bag is free to come out of the commode. Because there is a small open area in the bottom of the exterior plastic film forming the outer layer of the bag, the whole thing is placed inside a plastic bag of a size just large enough to easily contain it and a wire twist tie is applied to close it. That container is thereupon disposed of as unit.

A fresh three-layer bag is installed in the clean commode chamber using a toggle clamp to attach the neck of the bag to the end of the transport tube. The bottom of the bag, recognized by the opening in the outer film layer, is draped over a fan separator air outlet screen at the bottom of the commode so that air is drawn from the inside of the bag. Because the innermost layer of the bag is a filter material producing a finite pressure loss, and the middle layer is an open, reticulated foam standoff material with negligible pressure loss, the bag will become inflated by the suction. Closing the front door then allows the bag to take its normal position, filling the entire body of the commode.

At a packing density of 53 percent, the volume of the existing Space Shuttle commode can contain the feces and paper wipers required for a nominal 210 man-day capacity. If the three-layer bag were removed after 7.5 days of nominal use by a seven man crew, the full 210 man-day capacity could be provided using a nominal 52.5 man-day capacity for the bag, and the bag could be changed three times in a thirty-day flight. On this basis, the packing density before compaction would need to be only 17 percent. If compaction density is 50 percent, external storage volume will be .062 m (2.2 ft³). Changing of the three-layer bag in flight could be accomplished with nearly the same ease as on the ground, where 3.8 minutes is expected to be sufficient for one person. Furthermore, because the bag is plugged and clamped while the fan separator is running, there is no feasible way in which any waste matter could escape despite the weightlessness of orbital flight.

Note should be taken of the fact the Gore-Tex type filter layer at the inside of the bag is commonly used as a moisture resisting ventilating layer in outdoor garments. On this basis, there may be little concern over its integrity during handling in bag fabrication, installation, use and removal, or in final storage.



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A further note may be taken of the circumstance where wastes for some reason contain active bacteria while in storage. Gases generated by bacteria in feces accumulate over a period of time and consist primarily of CO_2 and CH_4 . Although harmless ingredients of the normal space cabin air, they could cause the twist-tied storage bag to distend and eventually occupy more volume than may be allotted. In such a case, reliance is placed on the fact that a twist-tied bag is not air-tight, and a bag squeezed by adjacent bulk of stored material will subside.

A final observation is significant. Since the Gore-Tex PTFE lining layer is actually a hydrophobic filter material, it will tend to retain moisture while permitting the passage of air. Consequently, an copious wet discharge into the commode, as from diarrhea, would be fully contained. No contamination of the bag exterior or of the commode interior would be expected which could become a factor in the changing of bags in flight.

An experiment was conducted on a mock-up of the outer, impervious layer of the three-layer bag to demonstrate that fan suction would collapse the plugged bag without the necessity of a fastening at the bottom. The bag was actually forced against the simulated commode bottom, while suction drew the air out of it and collapsed it upon the simulated waste contents.

Three-Layer Bag Construction - As in Figure 4 the innermost layer is made of Gore-Tex type felt-backed PTFE expanded micron filter material. Since area is $.65 \text{ m}^2$ (7 ft^2), there is sufficient area to keep pressure loss at or below $.12 \text{ N/m}^2$ (5 in H_2O) at $.85 \text{ m}^3/\text{min}$ (30 cfm) airflow. Outboard of the filter layer is a 5 mm ($3/16$ in) layer of fairly stiff reticulated, polyurethane foam acting as a standoff layer, supporting the $.12 \text{ N/m}^2$ (5 in H_2O) pressure on the filter layer, and draining it to the screened outlet at the bottom of the commode bowl. Outside the standoff layer is an impervious film layer of tough, thin polyethylene material possibly with imbedded scrim for reinforcement. This impervious layer has an opening at the bottom to expose the standoff layer to the screen covering the air outlet duct port of the commode proper. It serves to protect the interior surface of the commode from any liquid contamination that might seep through the normally hydrophobic filter inner layer of the bag. It further serves to provide a tough and integral containment of the compacted wastes as the fan suction squeezes it down about them, since the impervious film layer has an opening at the bottom, reliance is placed on the comparatively thick reticulated foam to protect the inner filter layer from bursting or tearing in this zone while undergoing compaction or handling. As the bag is plugged at its neck and clamped there, and essentially all the air has been drawn out of the bag, it is relatively compact, tightly enclosing its contents, and is easily inserted into a tough, impervious film garbage bag to be twist-tied and stored in the vented wet-waste compartment. Any gases generated will leak through the twist-tied neck of the garbage bag if there is sufficient volume of gas generated to distend it. Size and shape of the garbage bag will be defined to contain the three-layer bag and contents for fifty-six man-day accumulation of waste. That would permit bag changeout after a seven day eight-man mission, or once per week while in flight on an extended duration.

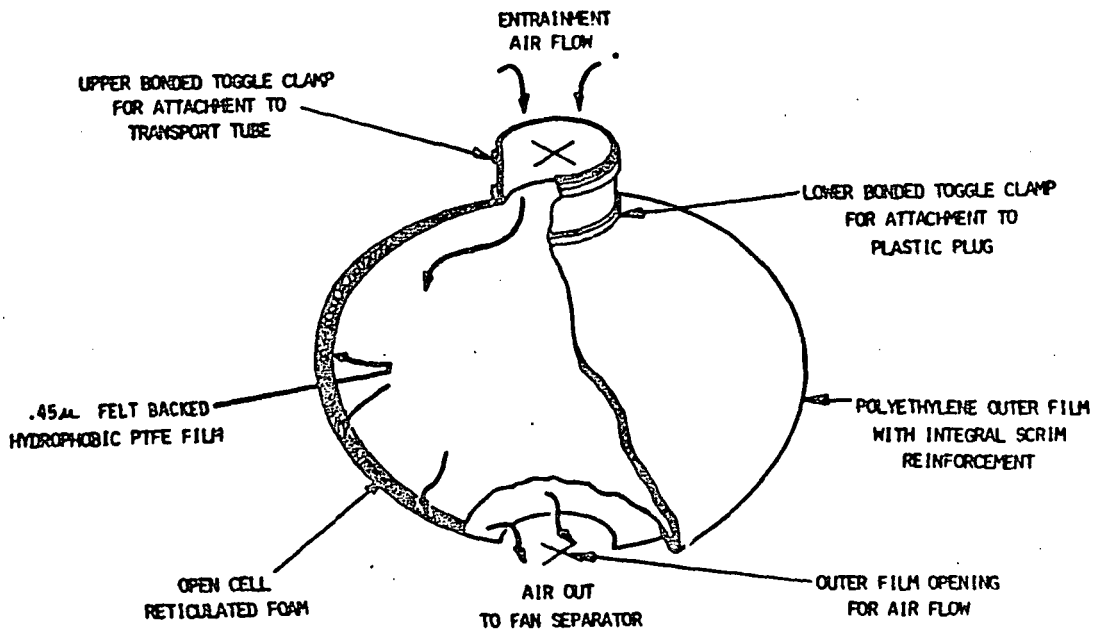


Figure 4
THREE-LAYER BAG



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Manufacture of the three-layer bag takes place in stages. First orange-peel gores are cut from the commercially available felt-backed PTFE Gore Tex filter material and are stitched together on a sewing machine leaving one or more seams open to facilitate handling. Closure is completed by hand-stitching over a collapsible form that is removed through the neck of the bag. While still on the form, gores of polyurethane reticulated foam cut to orange peel shape are placed over the felt backing side of the Gore-Tex filter layer, and are butted and cemented into place with widely spaced drops of quick-drying cement. On a separate form, the exterior impervious film layer is built up also of cut gores, but to obtain adequate sealing, they are made to overlap and are sealed into position with contact cement. One seam left open enables it to be placed over the standoff layer where it is sealed and cemented to the filter layer around the neck. The form is thereupon collapsed and withdrawn through the neck. The two toggle clamps are bonded to the neck of the bag to improve convenience in installation and removal in the commode. In Figure 5 a tail is shown ducting air to the outlet location. This tail permits a twist-tie to be applied before the bag is removed from fan suction, as an alternative concept, to avoid the possibility of partial re-inflation during handling.

Plug For Three-Layer Bag - A molded thick-walled flexible plastic plug, as in Figure 6, is provided to close the three-layer bag lining the front door commode. This plug has two ridges molded into it. A ridge or lip around the top snaps into the slide valve groove, positioning the plug. A ridge around the bottom holds the toggle clamp from sliding off the bottom, while the top ridge holds it from sliding off the top, once the bag has been disconnected from the transport tube. A ridge on the outside bottom of the transport tube prevents the clamped bag from sliding off the transport tube. Toggle-type hose clamps are desirable for attaching the bag, as they are quickly applied and removed, and hold with adequate tightness.

Procedure For Three-Layer Bag Installation -

- (1) Insert fresh three-layer bag into the commode, and slide neck of bag over the lower end of the transport tube.
- (2) Attach a toggle-type hose clamp around the neck of the bag, fastening it to the transport tube.
- (3) Drape outer layer vent at bottom of bag so that it covers the air outlet screen at the bottom of the commode.
- (4) Open the slide valve, thereby starting the fan separator and admitting airflow through the transport tube to inflate the bag.
- (5) When bag is inflated, make a visual inspection for proper positioning and inflation and close the door, making the commode ready for use.



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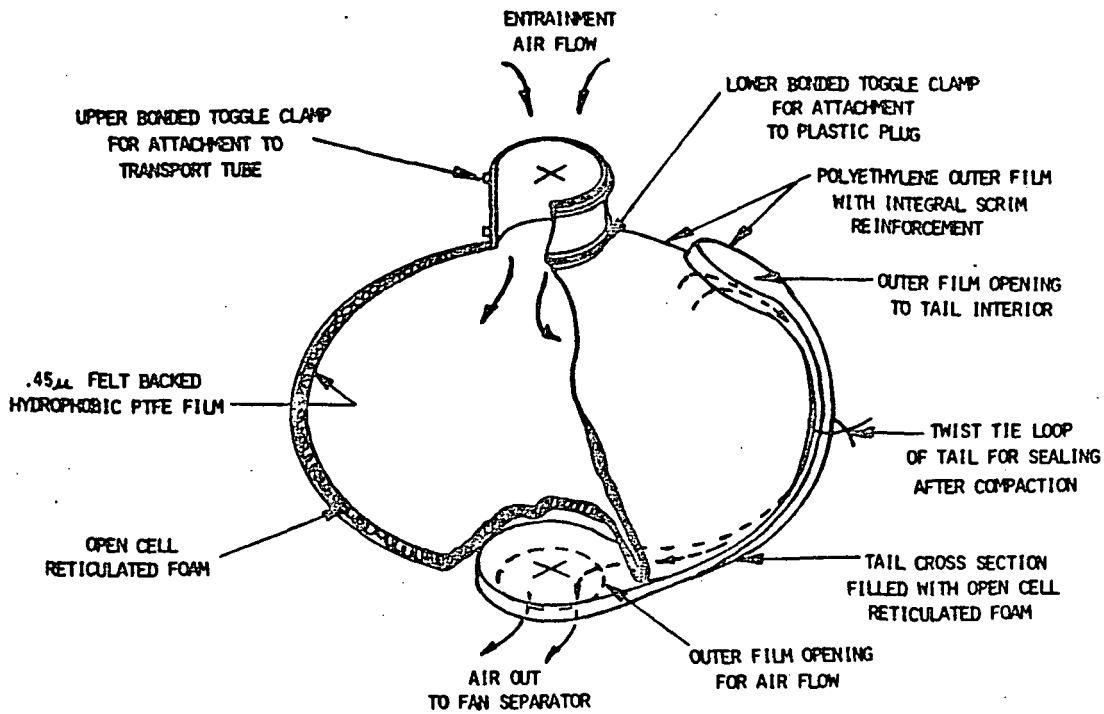


Figure 5
THREE-LAYER BAG WITH AIR OUTLET CLOSURE

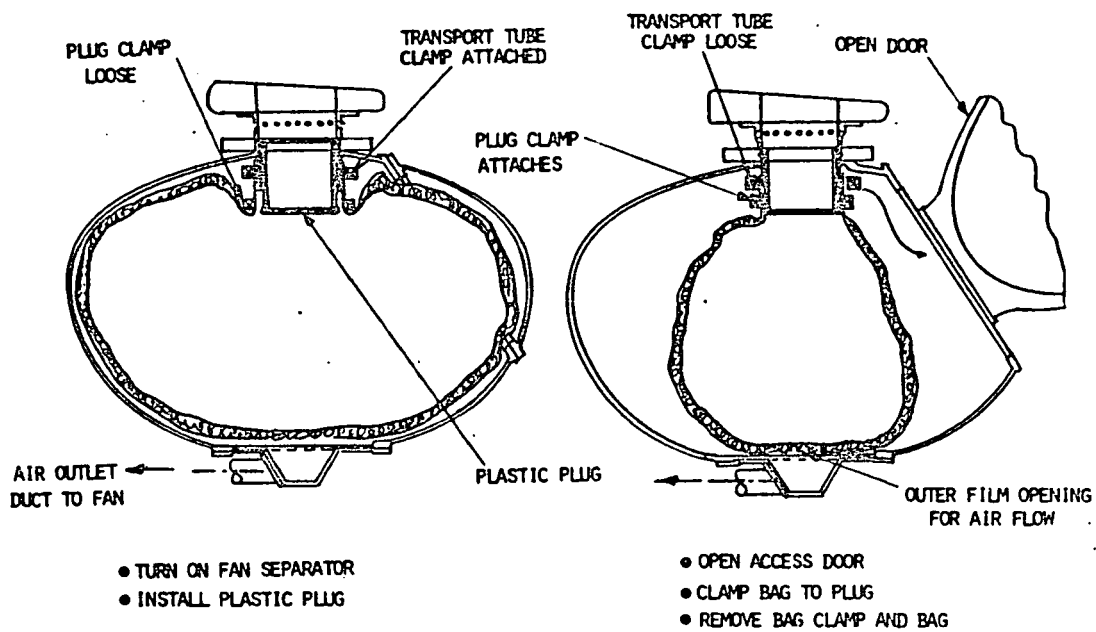


FIGURE 6
PLUGGING AND REMOVAL OF THREE-LAYER BAG



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Procedure For Three-Layer Bag Removal -

- (1) Open the slide valve, thereby starting the fan separator.
- (2) Insert cup-shaped flexible plastic plug into transport tube until top lip snaps into slide valve slot.
- (3) Open the front door of the commode, exposing the exterior surface of the three-layer bag to the cabin air, thereby collapsing the bag from fan suction and compacting the contents.
- (4) Reach hand inside front door, insure drape of collapsed bag around lower end of flexible plastic plug, and attach a toggle-type hose clamp around it.
- (5) Remove upper toggle-type hose clamp from around neck of bag at end of transport tube, and slide collapsed bag down from the transport tube and out the front door.
- (6) Insert plugged and collapsed three-layer bag into a properly sized plastic bag and close it with a wire twist-tie.
- (7) Dispose of tied bag in wet-trash compartment in flight, or remove from Space Shuttle on the ground.

These procedures have been listed in simplified form on Figure 7.

Drawings - Figures 8-10 are views from drawing SVSK 111105 which shows the front door commode drawn to scale.

5.1.2 Revolving Canister Commode with Cups

This design concept for a Space Shuttle commode, shown schematically in Figure 11, is aimed at rapid turn-around between flights, compaction of wastes for extended duration flights, and the ability to store wastes in a separate storage compartment. All the equipment fits within the Space Shuttle commode space envelope and all connections are the same. A 482 X 102 mm (19 inch by 4 inch) diameter dispenser for fresh cups is positioned on the wall near the supply of wipers. Two cups are placed within the commode by the user, covering the wastes, and are pushed down into a canister with a ramrod, compacting them. Seven canisters, each 431 mm (17 in) long by 102 mm (4 in) diameter, are arranged in a rotating cylinder bringing an empty canister into position when the previous canister is filled. Domed ends and cylindrical walls enable the body of the commode to resist the $.11 \text{ N/m}^2$ (16 psi) exterior pressure of cabin air while the contents are exposed to overboard vacuum venting. At the top, the slide valve, air jets and seat are identical to the existing Space Shuttle configuration. In Figures 15-19 the transport tube size has been increased in diameter, but it is believed not to be desirable. The seat has been moved forward, but within the original space envelope. In operation the



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COMPACTION

1. OPEN SLIDE VALVE
FAN STARTS
2. INSERT PLUG
3. OPEN FRONT DOOR
BAG COLLAPSES

REMOVAL

1. CLAMP PLUG
2. UNCLAMP TRANSPORT TUBE
3. REMOVE COLLAPSED BAG
4. INSERT IN SMALL BAG
5. TWIST TIE
6. DEPOSIT IN WASTE BIN

FIGURE 7
BAG WASTE COMPACTION AND REMOVAL



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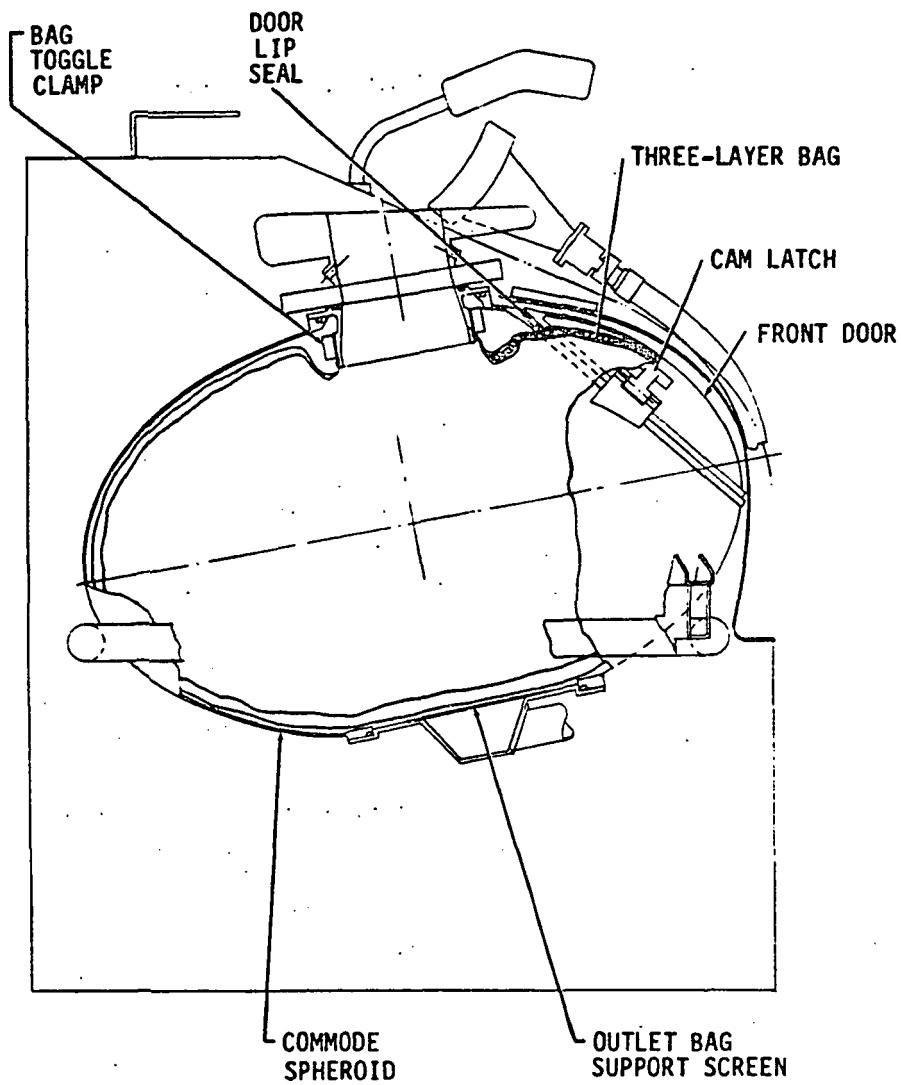


Figure 8
FRONT DOOR COMMODOE SIDE VIEW



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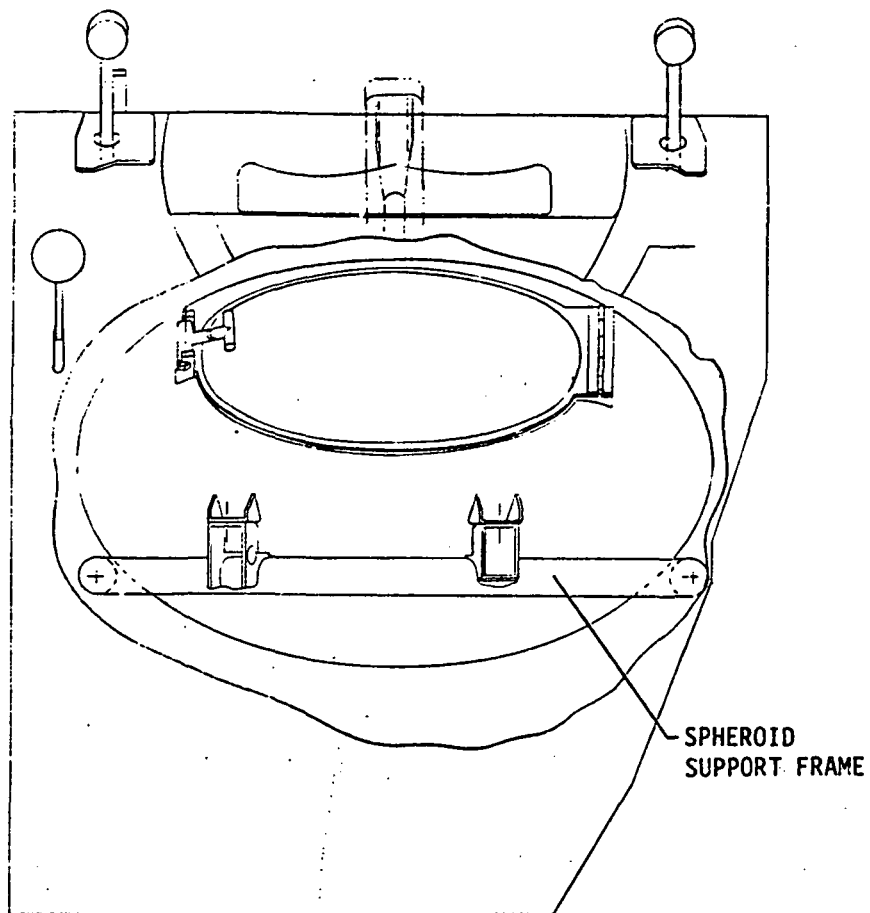


Figure 9
FRONT DOOR COMMODE FRONT VIEW

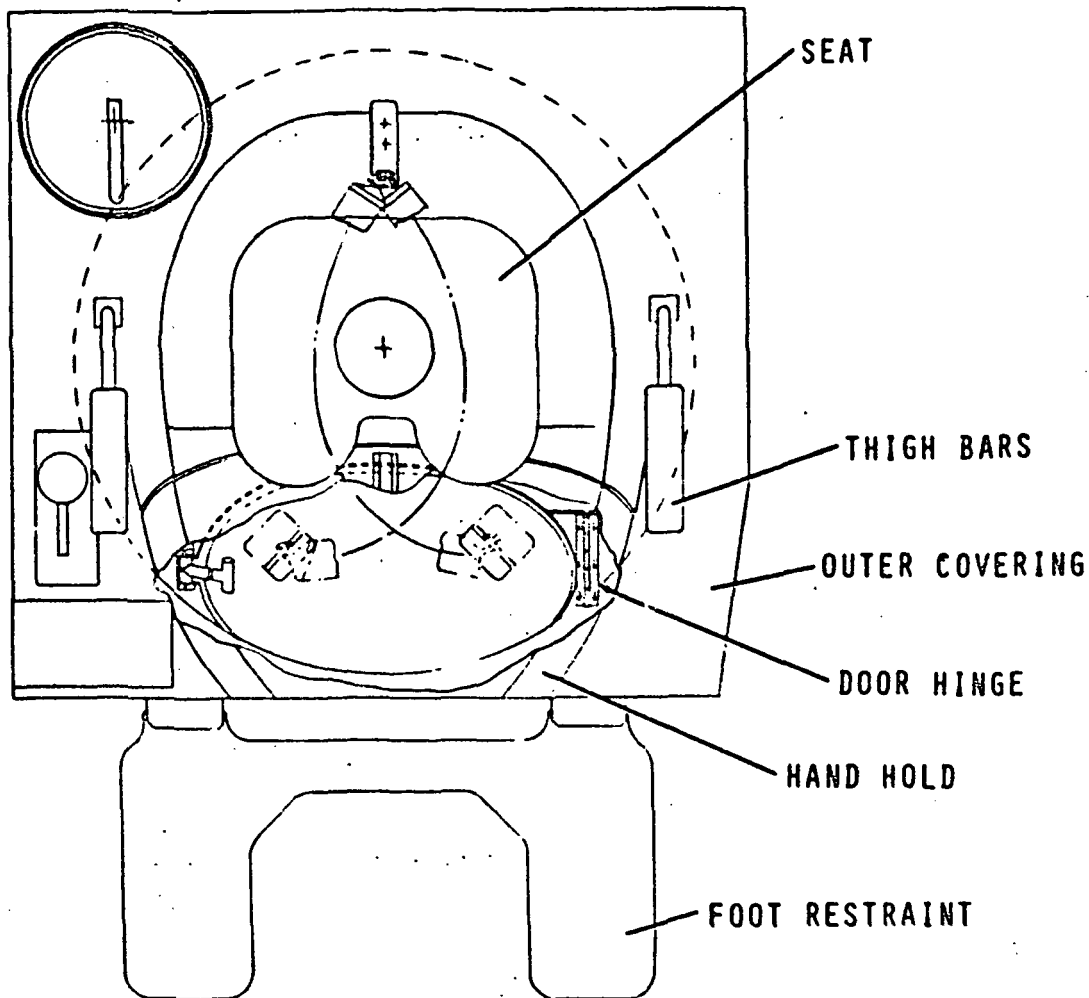


Figure 10
FRONT DOOR COMMODE TOP VIEW

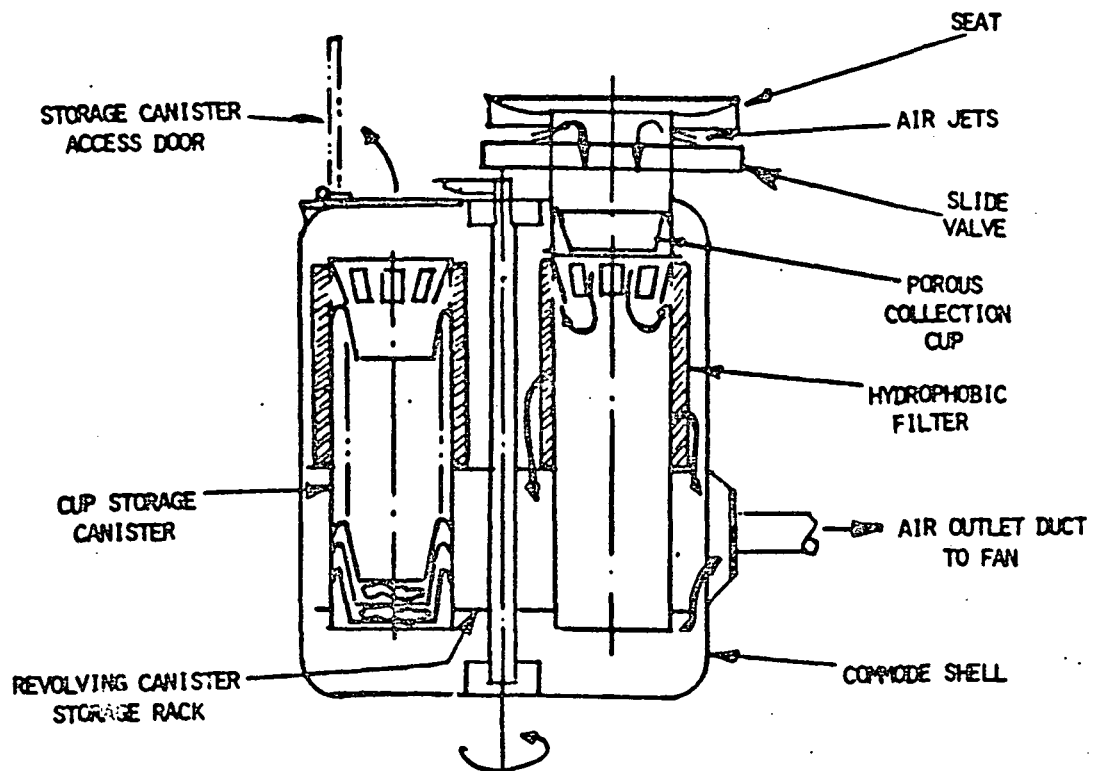


Figure 11
 REVOLVING CUP CANISTER COMMODE



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user opens the slide valve starting the fan separator, and fan air entrains the bolus of feces carrying it down the transport tube into a disposable cup at the top of a cylindrical canister. There the air vents through the porous sides of the cup, out of ports in the canister wall, into an annular chamber covered with a Gore-Tex filter, and into the interior of the commode. Air is exhausted from the commode by the fan separator as for the existing Space Shuttle commode. The transport tube and cup together provide a length of 279 mm (11 inches) in which a bolus can be entrained and transported. Upon deposition of the feces and paper wipers, fan air holds them against the wall of the cup. A second cup, this one lined with fabric reinforced Gore-Tex hydrophobic filter material is placed in the transport tube and is pushed down on top of the waste filled cup to compact the wastes, using a ramrod. The ramrod and its wide end is protected against possible contamination by the material of the second cup, which remains able to pass water vapor during vacuum venting. Both cups are pushed all the way down the canister until they either reach the bottom or reach previously compacted waste filled cups and force the wastes to fill the space between cups. The ramrod is taken out and held, while a fresh porous cup is inserted in the transport tube, then is used to push the cup into place against a low ridge around the circumference of the transport tube. Steps for compaction and removal of wastes are tabulated in Figure 12, with more detail in Figure 19. Leaf springs are positioned to cover the air vent ports in the canister wall to prevent the possibility of waste matter from being drawn in and clogging them as the loaded cup passes by. The Gore-Tex filter outside the canister is intended to trap any solid particles that may in some way be entrained and pass through the wall vent ports.

It will be noted that a deposit of feces and paper is covered by two cups before the user is ready to leave the commode. The next user makes a deposit in the cup already in place and adds two more cups in the manner described. The porous cup is made highly permeable to the fan separator air flow of 30 cfm. It will take the form shown in Figure 13 of a 16 mesh woven screen with an open weave fabric lining. It will thereby have sufficient stiffness to compact the feces and paper to a high degree while permitting water vapor to escape during venting to overboard vacuum. Each cup has a brim designed to act as a scraper to wipe the transport tube wall clean as it descends. Sufficient resilience or spring force will be obtained by squeezing the cup brim within the bore of the canister to insure a through wiping action. In Figure 14 an alternative collection cup is shown with a plastic film to protect the wall of the transport tube.

At the top of the active canister a seal closes the gap between it and the lower end of the transport tube, forcing the fan separator induced air flow to continue into the fabric-lined cup. In this way a bolus of feces or a paper wiper is entrained by air entering at the peripheral jets and is carried all the way into the cup where it must lie against the fabric, in spite of weightlessness. When a canister is full and there is no further room above the top two cups, a mark must remain visible beneath the leaf springs covering the vent ports. Actuation of the canister advancing handle will then convey the loaded canister out from beneath the transfer tube and will bring a fresh, empty canister into position. This action is mechanical by means of a locking detent which engaged prevents rotation in either direction, and by means of a ratchet and pawl which produce rotation in one direction by a specific amount. It is very much like the rotation of the cylinder of a revolver by drawing back the hammer.

COMPACTION

1. OPEN SLIDE VALVE
2. DEPOSIT WASTE
3. INSERT COMPACTION CUP
4. PUSH DOWN RAM ROD
5. INSERT HOLDING CUP
6. PUSH DOWN RAM ROD

REMOVAL

1. OPEN SLIDE VALVE
2. INSERT BAIL
3. EXTRACT CANISTER
4. DEPOSIT IN WASTE BIN

Figure 12
CUP WASTE COMPACTION AND REMOVAL

TWO TYPES: 1. COLLECTION CUP
2. COMPACTION CUP

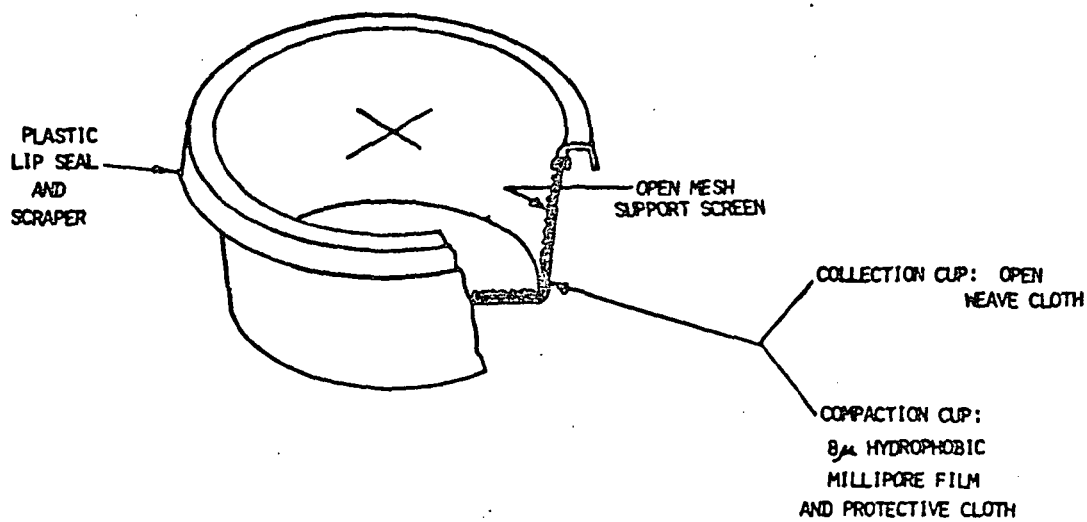


Figure 13
COMMODE CUP

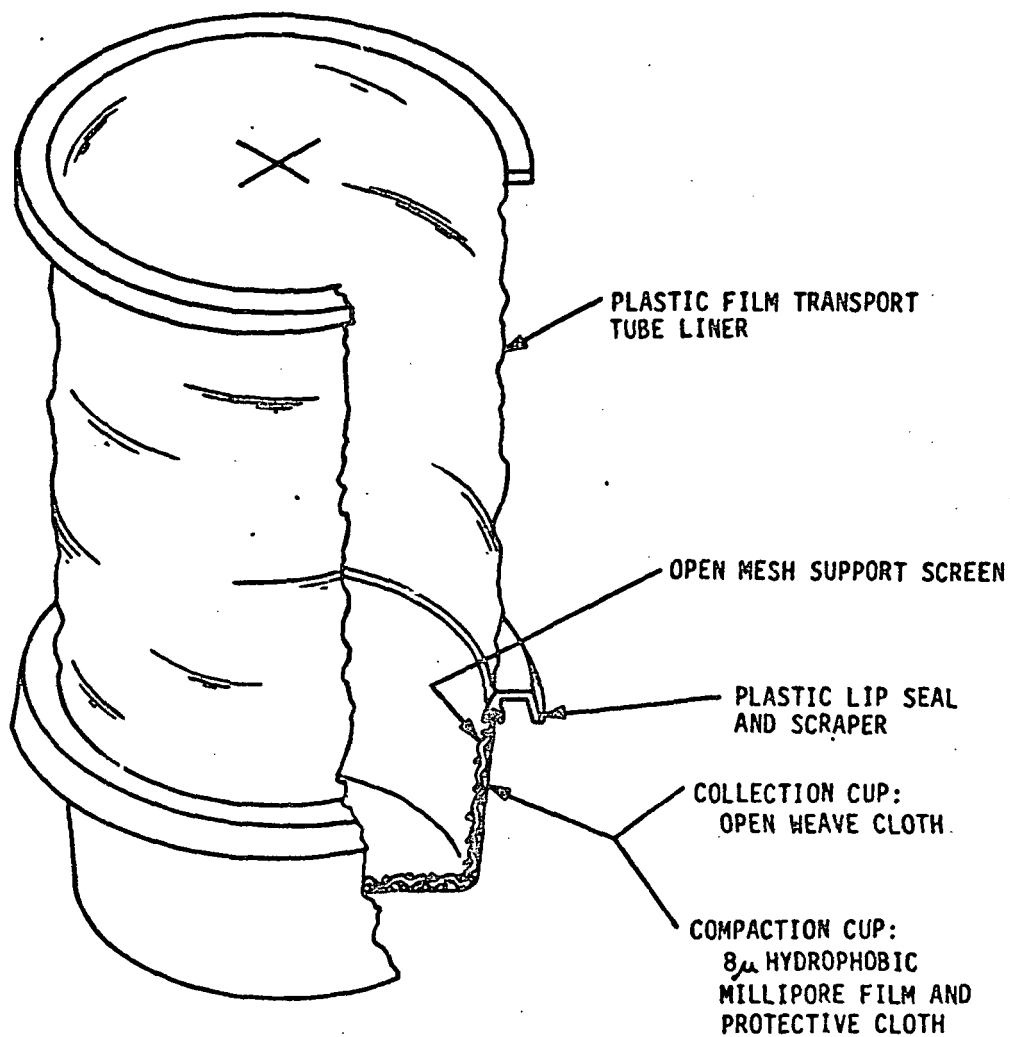


Figure 14
ALTERNATIVE COLLECTION CUP



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When all five canisters are full, or at the end of a flight, an unloading port immediately behind the commode seat is opened. This door with a face seal is mounted on a hinge and latch designed to have clearances taken up by spring forces so that uniform contact at the sealing face is obtained in the direction of the cabin air pressure force. By reaching into the exposed canister with a spring wire bail, two opposite holes in the canister wall are engaged and the bail is used to pull the canister out of the revolving cylinder that holds the seven canisters. A new, empty canister is inserted into the vacated position and the cylinder lever is actuated to the next and succeeding positions for unloading and replacement. For extended missions additional empty canisters would be stowed nearby. Seven canisters each 102 mm (4 inches) in diameter and 406 mm (16 inches) long would be sufficient for a mission of 95 man-days, if compaction were 100%. If it were 75%, capacity would be for 71 man-days. See Figure 27. Full canisters would be stored in a ventilated compartment.

At long intervals, of possibly one year, the Gore-Tex filters surrounding the canister position should be replaced, to insure continuing low pressure loss. At this time the entire interior of the commode would be cleaned by use of a hose nozzle injecting pumped hot water and detergent solution, while a suction hose drains the bottom. Revolving cylinder bearings would be non-metallic teflon and require no lubrication.

A question may arise as to the consequences of a wet discharge into the commode, as from a case of diarrhea. Contamination of the walls of the transport tube will be avoided by the entrainment air flow to some point below the slide valve. Beyond, insertion of the two subsequent cups will wipe clean the walls of the transport tube and canister. Moisture will not return through the hydrophobic filter medium of the cup immediately above the wastes. Moisture seeping through the fabric wall of the lower cup along with the fan air will be retained by the much larger Gore-Tex filter surrounding the canister, until it is evaporated by the circulating air flow. At that point any increased pressure loss from moisture will tend to diminish. Such evaporated moisture must pass through the odor and bacteria filter before it can reach the cabin. Support for this possibility lies in the fact that an 8 micron hydrophobic filter has a $.028 \text{ N/m}^2$ (4 psi) bubble point, while with $.122 \text{ m}^2$ (190 sq in) area there will be only $.05 \text{ N/m}^2$ (2 in H_2O) pressure loss at $.85 \text{ m}^3/\text{min}$ (30 scfm) airflow.

The drawing SVSK 111104, Figures 15-19, of the revolving cup canister commode shows it to fit entirely within the Space Shuttle commode space envelope. There is a modification in that the seat is located 190 mm (7.5 inches) forward of the original position. Both thigh bar restraints have been moved forward a like amount to compensate. Leaving the two foot restraints in their original position makes it possible to close the compartment door as before. The crew member will note the change as one involving somewhat more sharply bent knees while seated in the new position. This does not produce any anatomical interferences. Hand holds will again be placed behind the calves of the legs, but in a more nearly vertical orientation requiring the wrists to be turned through a somewhat greater angle. The drawing shows 5 canisters each 127 mm (5 inches) in diameter which would provide the desired capacity. Consideration of the developed status of the urinal-seat dimensions, and the

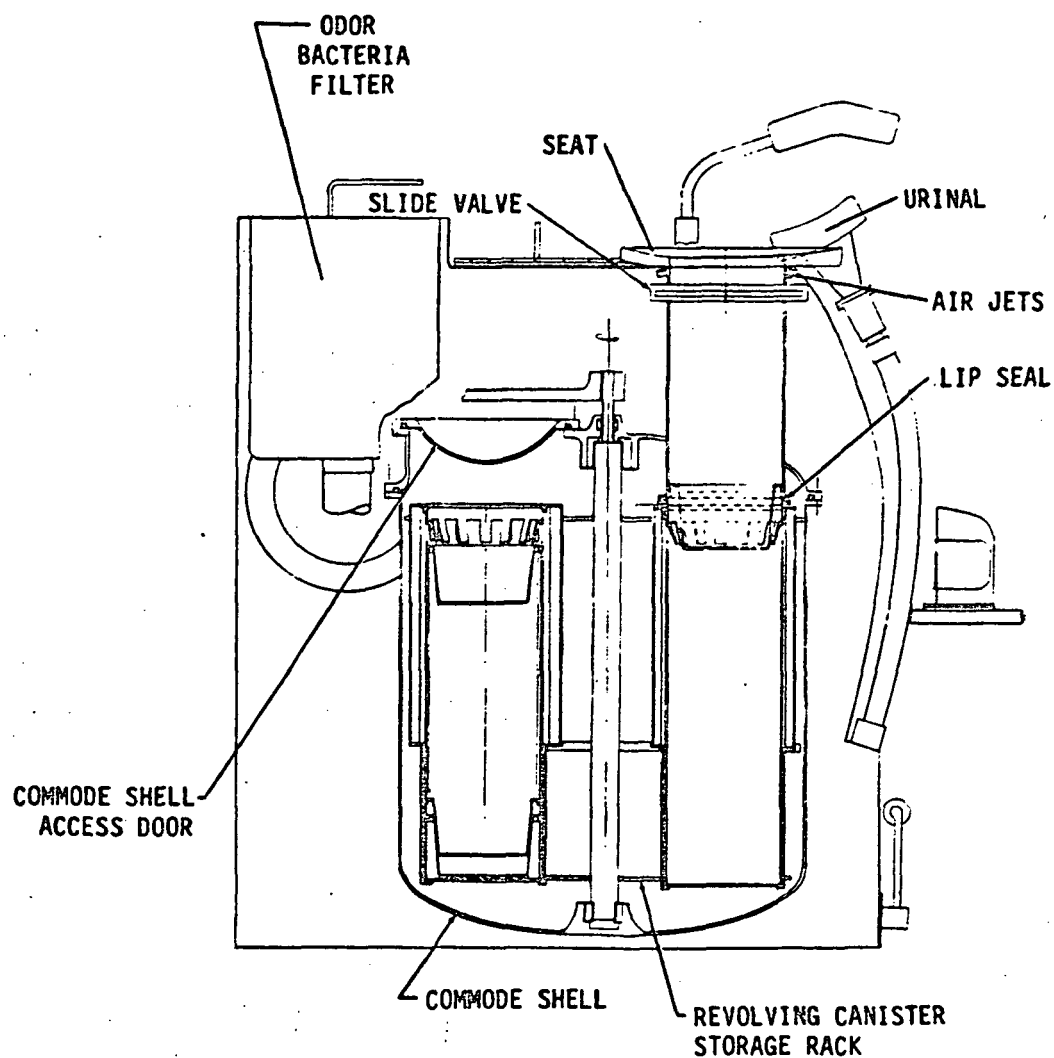


Figure 15
REVOLVING CANISTER COMMODE SIDE VIEW



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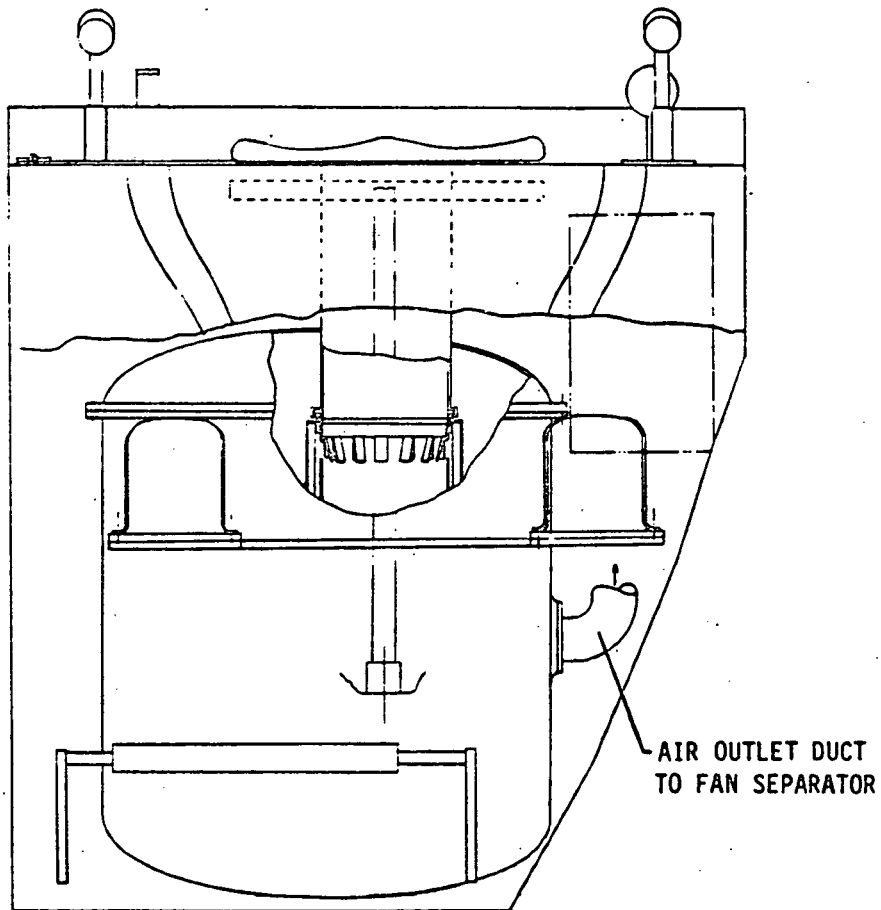


Figure 16
REVOLVING CANISTER COMMODE FRONT VIEW

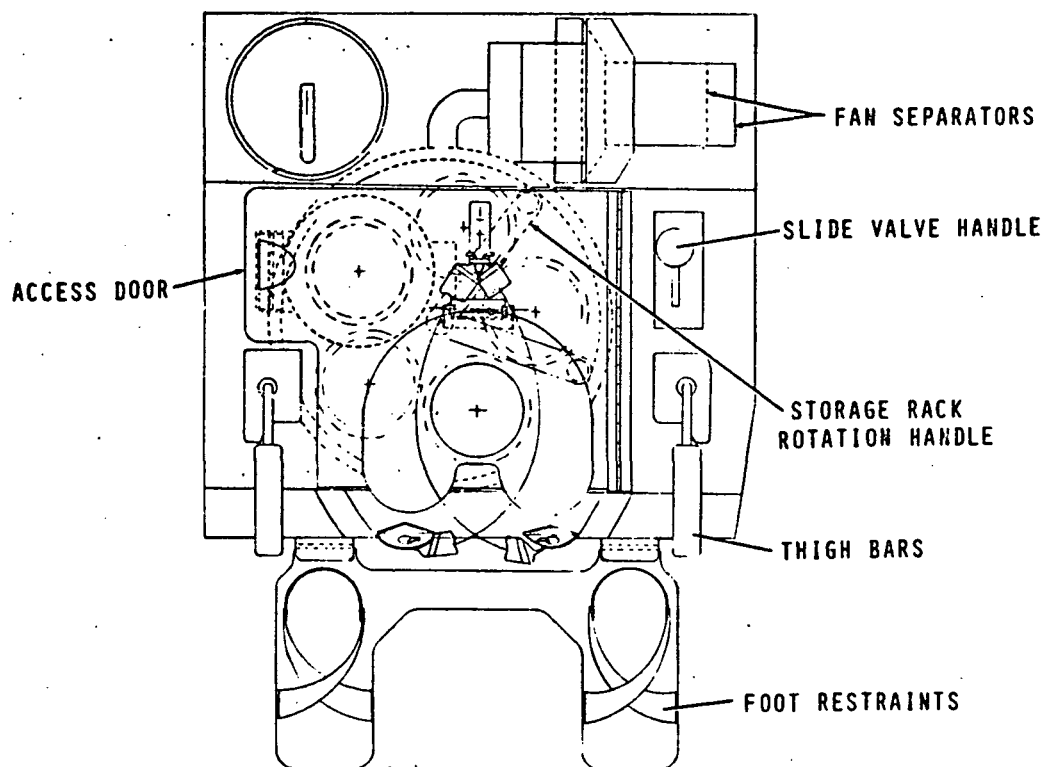


Figure 17
REVOLVING CANISTER COMMODE TOP VIEW

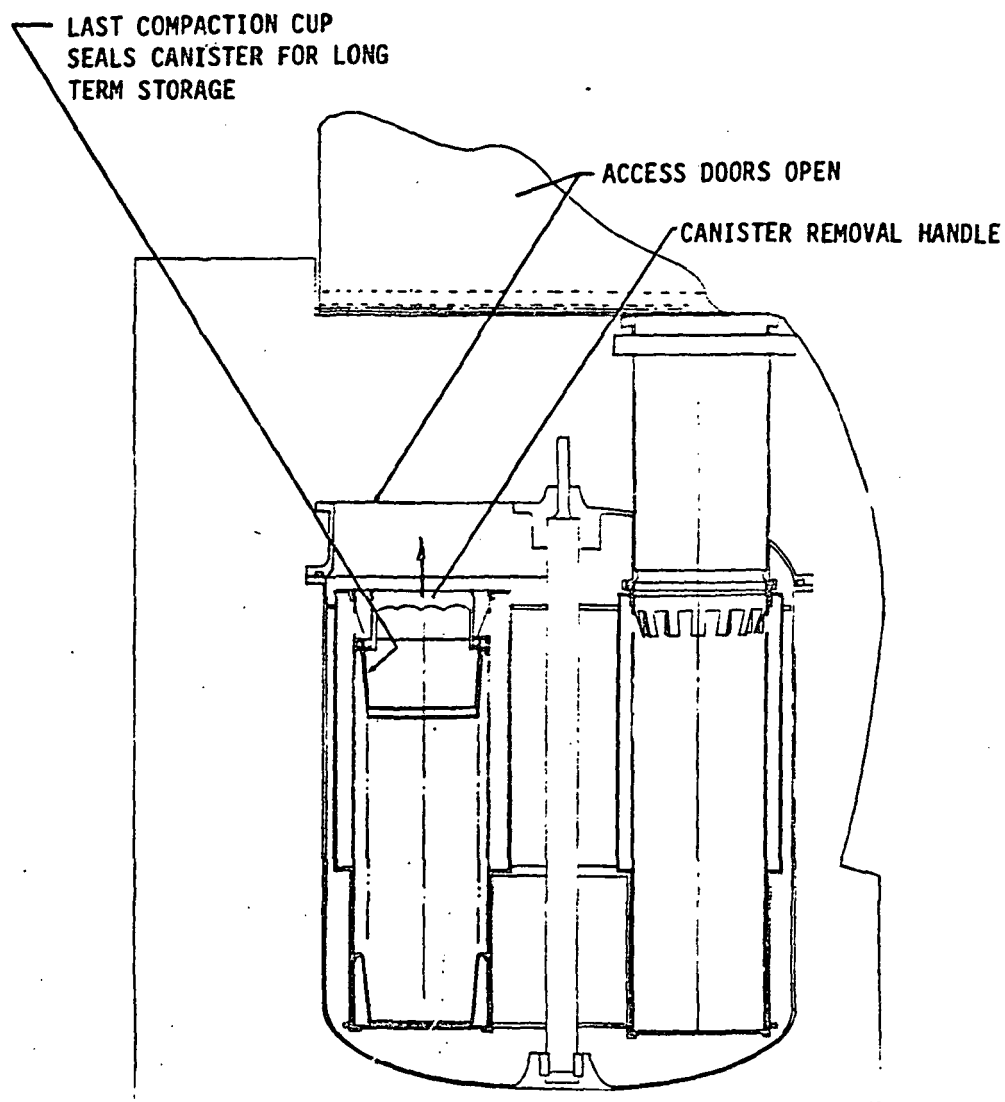


Figure 18
REVOLVING CANISTER ACCESS

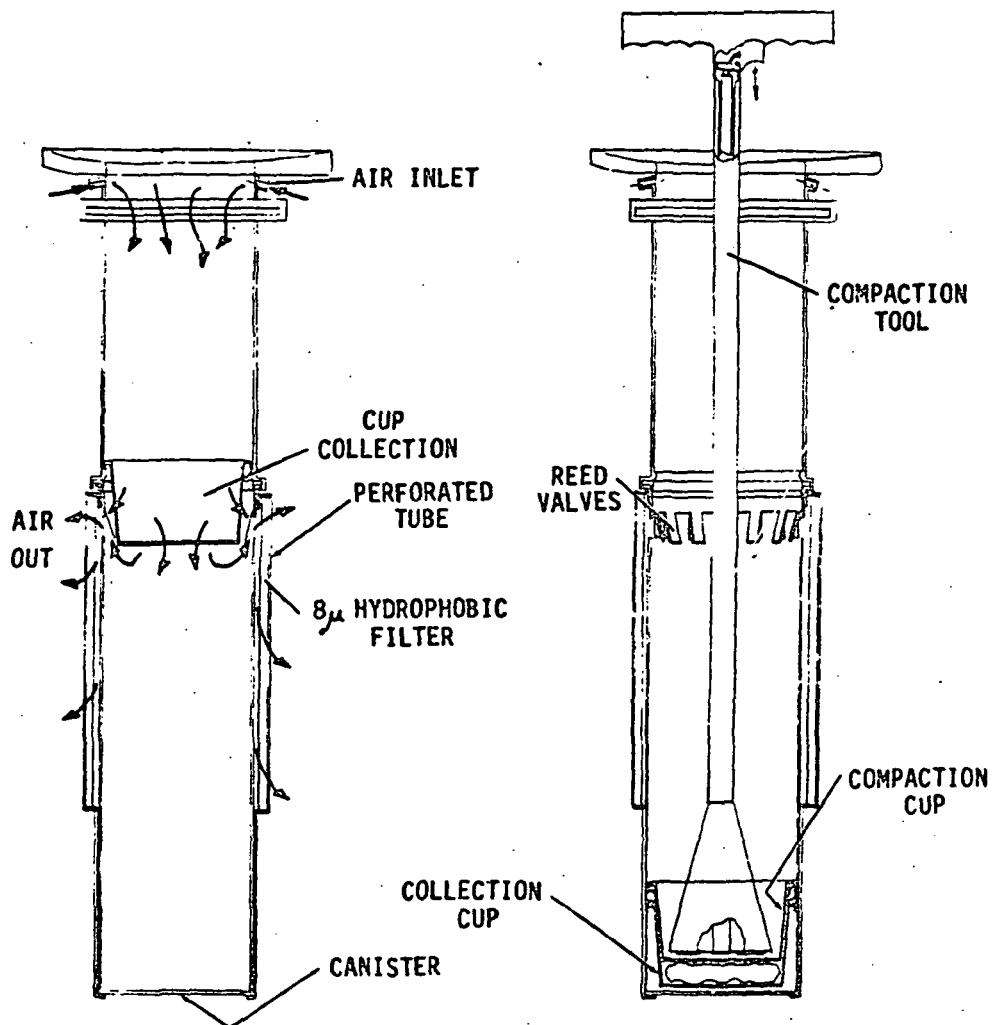


Figure 19
CUP COMPACTION



4 in diameter transport tube with air jets and slide valve has led to the conclusion that these should not be disturbed. Therefore, although it was too late to revise the drawings, the actual design concept evaluated in this report has 71 man-days capacity and 7 canisters, each 102 mm (4 inches) in diameter.

Volume for the seven canisters accommodates a nominal 71 man-day deposit of feces and wipers. Thus a Space Shuttle mission of 7 persons for 10 days is accommodated. A mission requiring 210 man-days capacity is accomplished by storing 14 additional canisters and 2 additional cup supplies. Storage for these canisters and cups, while unused or used must be provided outside the space envelope defined for the present Space Shuttle commode. On this basis an additional $.051 \text{ m}^3$ (1.8 ft^3) would be required to store the canisters in a rectangular space, and the additional cups could be stored within them.

When changing canisters, the inside of the hydrophobic Gore-Tex filter should be viewed to ascertain that it does not need changing. If it does, the old filter can be pulled out the same opening from which the canister is removed. A new filter in its cylindrically shaped woven mesh frame can be slid in and snapped into place.

Cup Commode Flight Experiment - In Figure 20, an experiment is illustrated in which a cup canister can be inserted in the Shuttle commode before flight, and can be extracted from the commode during flight after it has been filled by actual use. This experiment necessitates a special design that will fit the commode. It will remain clean on the outside because it will start from the ground when the commode is empty. Because its size is necessarily smaller than that of a canister designed as a part of a canister type commode, its capacity will be limited to perhaps six or eight uses. The last cup inserted seals the canister, and it is removed with an inserted bail. Finally, it is loaded into a protective plastic bag, loosely twist tied, and stored in the wet trash compartment for inspection after landing.

5.1.3 Stationary Canister Commode With Cups

A variation on the revolving canister commode with cups for collection and compaction of wastes is illustrated in Figures 21-23 which comprise views from drawing SVSK 109313. In this configuration, the canister and the collection and compaction cups are retained unchanged from the revolving canister commode with cups. The major difference is in the reduction of the size of the pressure vessel that must withstand evacuation by overboard venting. As a consequence, the pressure vessel wall thickness can be significantly reduced, which, together with the large reduction in its surface area, results in an appreciable weight reduction, estimated at 6.8 kg (15 lbs) or more. A further advantage is in the reduction of space envelope volume devoted to the pressure vessel. This volume can be used to store filled canisters at cabin pressure with much improved efficiency. Furthermore, there is no longer a need to move the seat forward relative to the foot rests, and the exterior dimensions of all features can remain identical to those of the present Shuttle commode. A comparison of canister dimensions is tabulated in Figure 27. There it is noted that storing nine filled canisters within the commode as outlined in

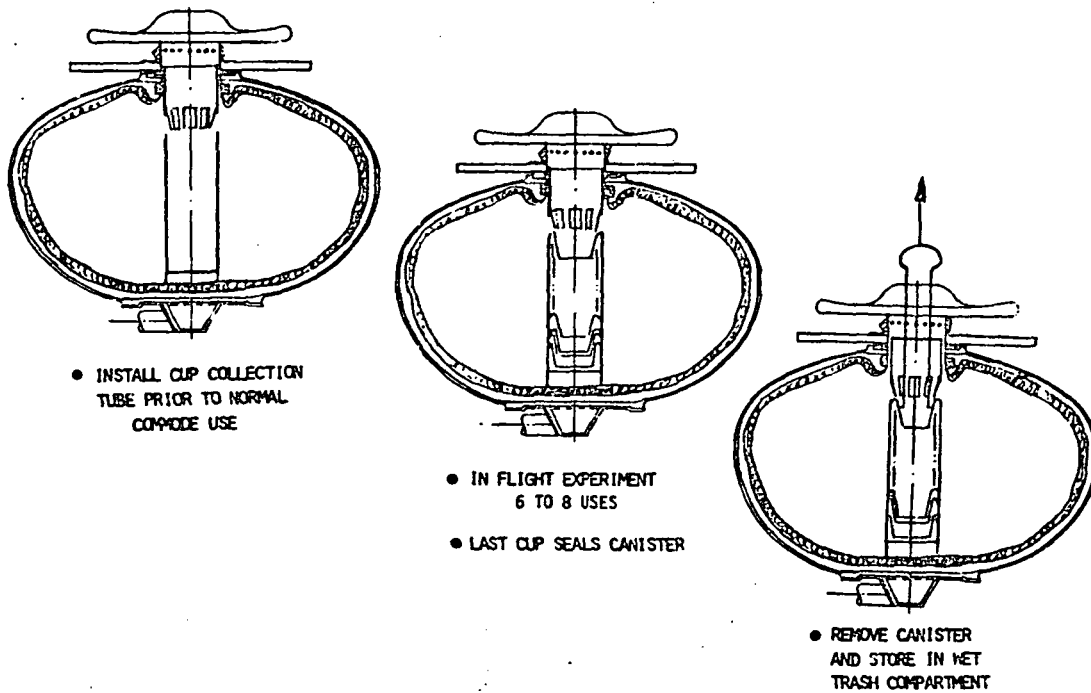


Figure 20
CUP COMMODE FLIGHT EXPERIMENT

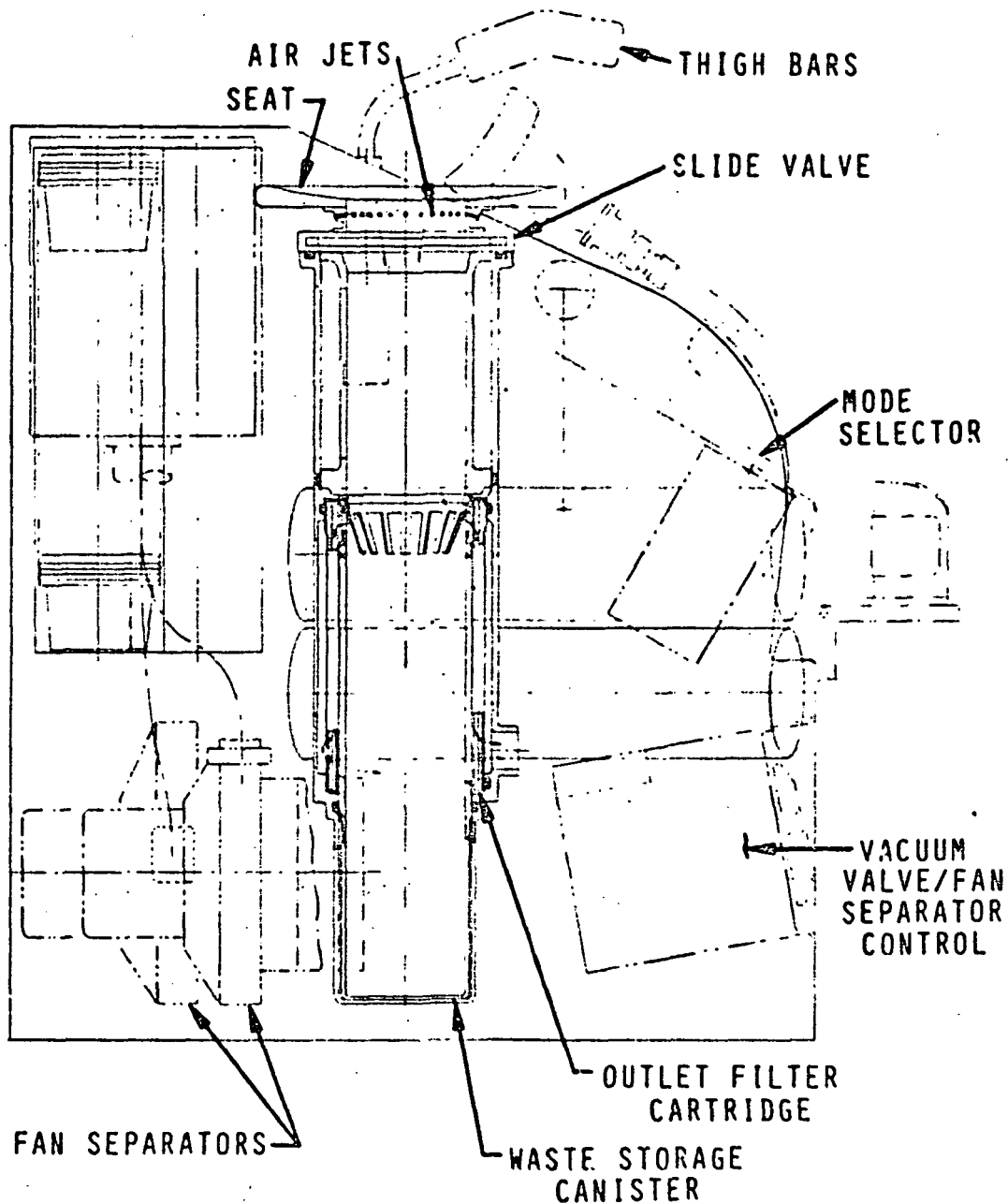


Figure 21
STATIONARY CANISTER COMMODE SIDE VIEW

CRANFILL
OF POOR

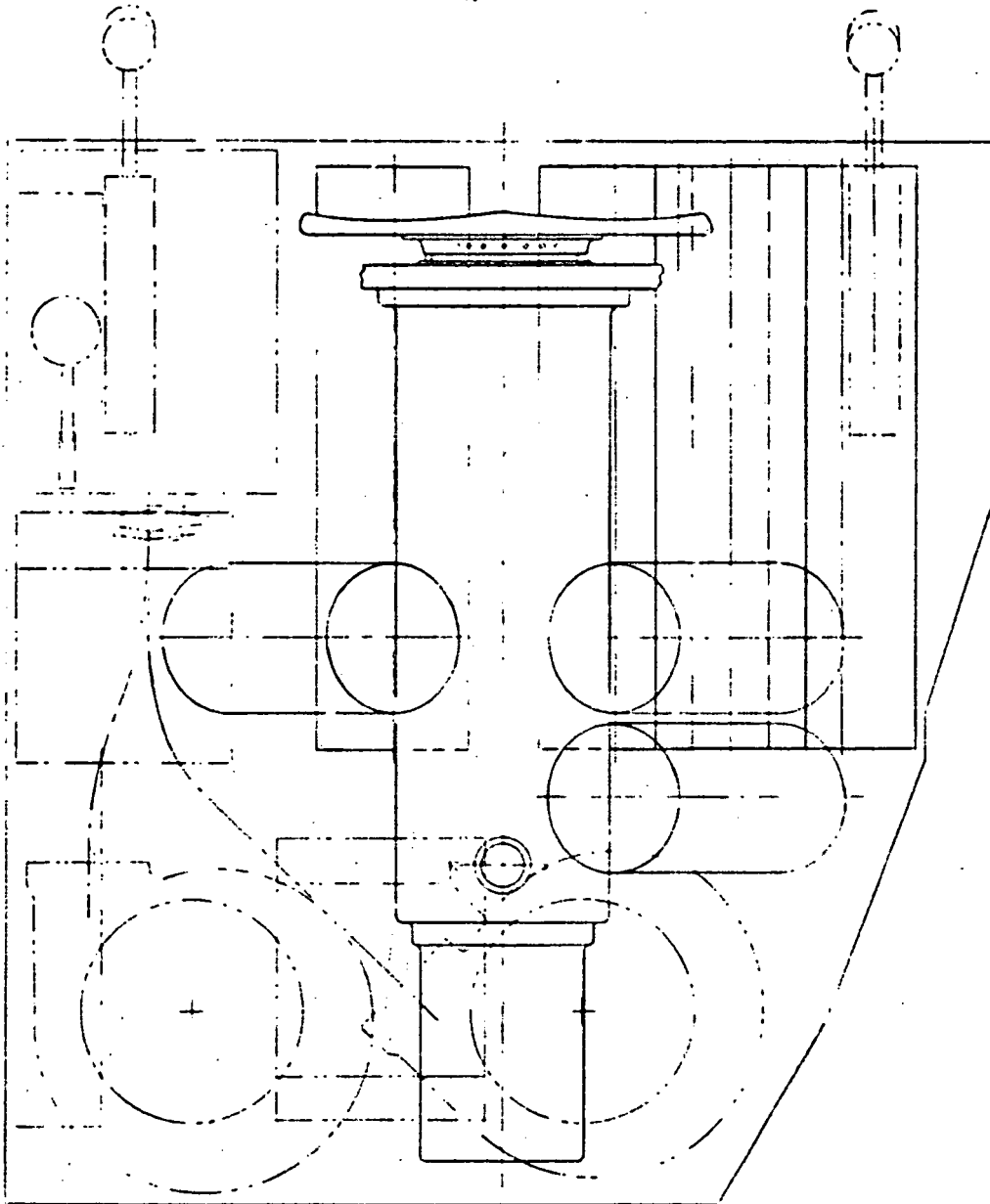


Figure 22
STATIONARY CANISTER COMMODE FRONT VIEW

ORIGINAL
OF FOUR QUARTERS

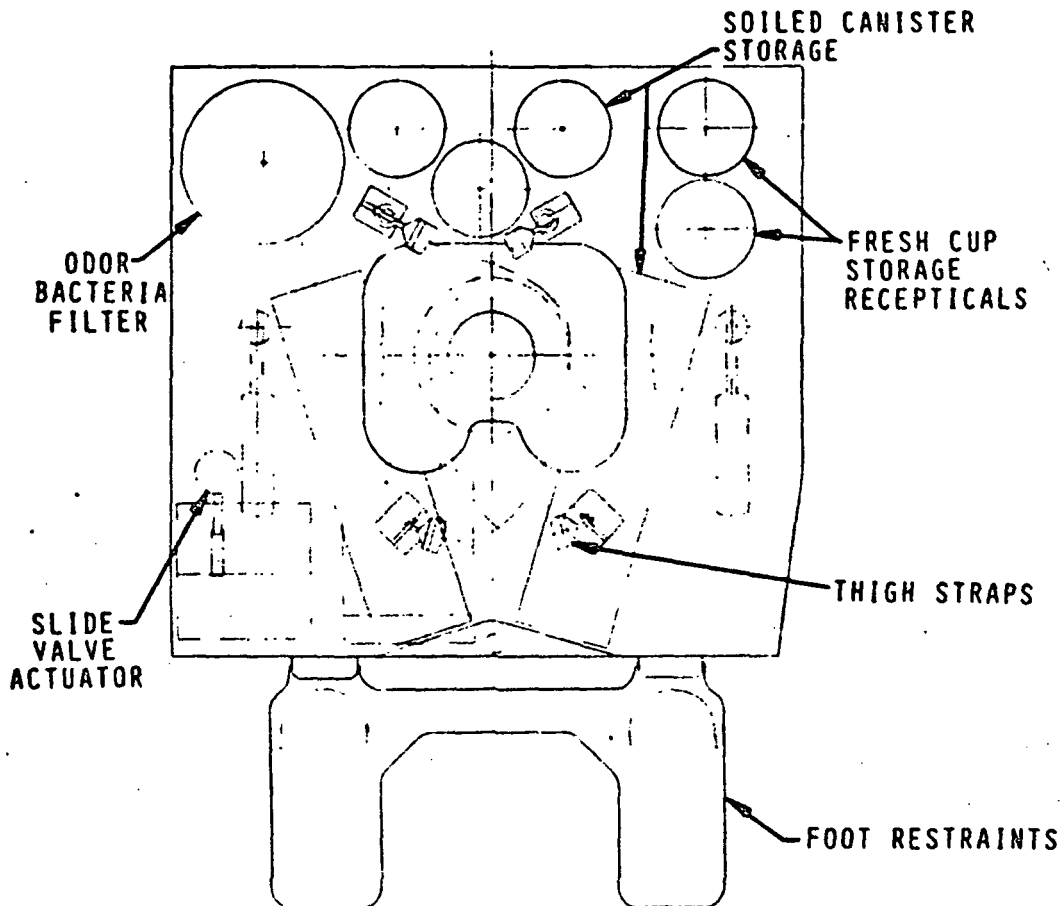


Figure 23
STATIONARY CANISTER COMMODE TOP VIEW



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Figures 21-22 provides an estimated 130 man days capacity. Storage of unused empty canisters and of filled canisters in the commode is provided at cabin pressure in thin walled compartments each vented to the wet waste ventilation line which vents overboard through a small orifice for odor control. These compartments need close fitting doors, but do not require seals, since the very low ventilation flow is inwards. Removal of a canister from the commode is by raising the seat - air jet - slide valve unit relative to the commode. That provides access to the transport tube and canister. A long handled bail is extended to catch a pair of the spring leaves and is used to withdraw the canister and the transport tube. A new canister is inserted, the transport tube is replaced, and the top of the commode is closed. A hinge and latch should be sufficient for attaching the commode top because both fan suction and overboard venting provide pressure assistance to the closure and the seal. The slide valve operating lever may be attached to the seat, or it can remain attached to the commode body and connect to the slide valve with a flexible shaft. As with the revolving canister commode the Gore-Tex filter surrounding the canister is accessible for exchange at intervals, and is easily reached with the canister removed.

5.1.4 Stationary Canister Commode With Disks

A further variation on the canister commode concept takes advantage of useful features devised for the revolving canister cup commode and the stationary canister cup commode. No deviations are made in the seating position relative to the present Shuttle commode. As seen in the sketches on Figures 24-25, a single compaction disk molded of a slightly elastomeric material is used instead of two cups. The Gore-Tex filter surrounding the canister is made integral with the canister as insurance that the exterior surfaces of the canister will always be sanitary for handling. The leaf spring valves previously used to prevent waste from clogging the air outlet passages have been eliminated, on the basis that they constitute a geometrical difficulty which may lead to problems in development and in manufacture. Instead, the whole internal cylindrical surface of the canister is made of a rigid wire screen mesh, either of metallic or plastic material. This mesh allows the entrainment air to flow outwards into the surrounding space over a large area, as compared with the leaf spring covered ports. If soft wastes were to clog some of the mesh openings many more would remain open for air flow. The compaction disk has a skirt an inch long tapering in thickness to a thin edge at the bottom. This edge will scoop up any material, feces or paper in contact with the mesh and held there by the airflow. As this edge meets a chamfer at the top of the previously inserted compaction disk, followed by a slight outward draft, it will wedge its way into the crevice between the lower disk and the mesh wall and slide on past thereby coming to rest only when the waste contents within the skirt have been fully compacted. At the top of the compaction disk, there is a shoulder to engage the compaction piston which descends through the transport tube and canister to apply the compaction force. Continuing around the side of that shoulder, a thin lip extends out to the periphery, lightly pressing against the wall to scrape any residue remaining after the passage of the skirt. In effect, there are two wipings of the walls as provided by the two cups used in the cup canister configuration.

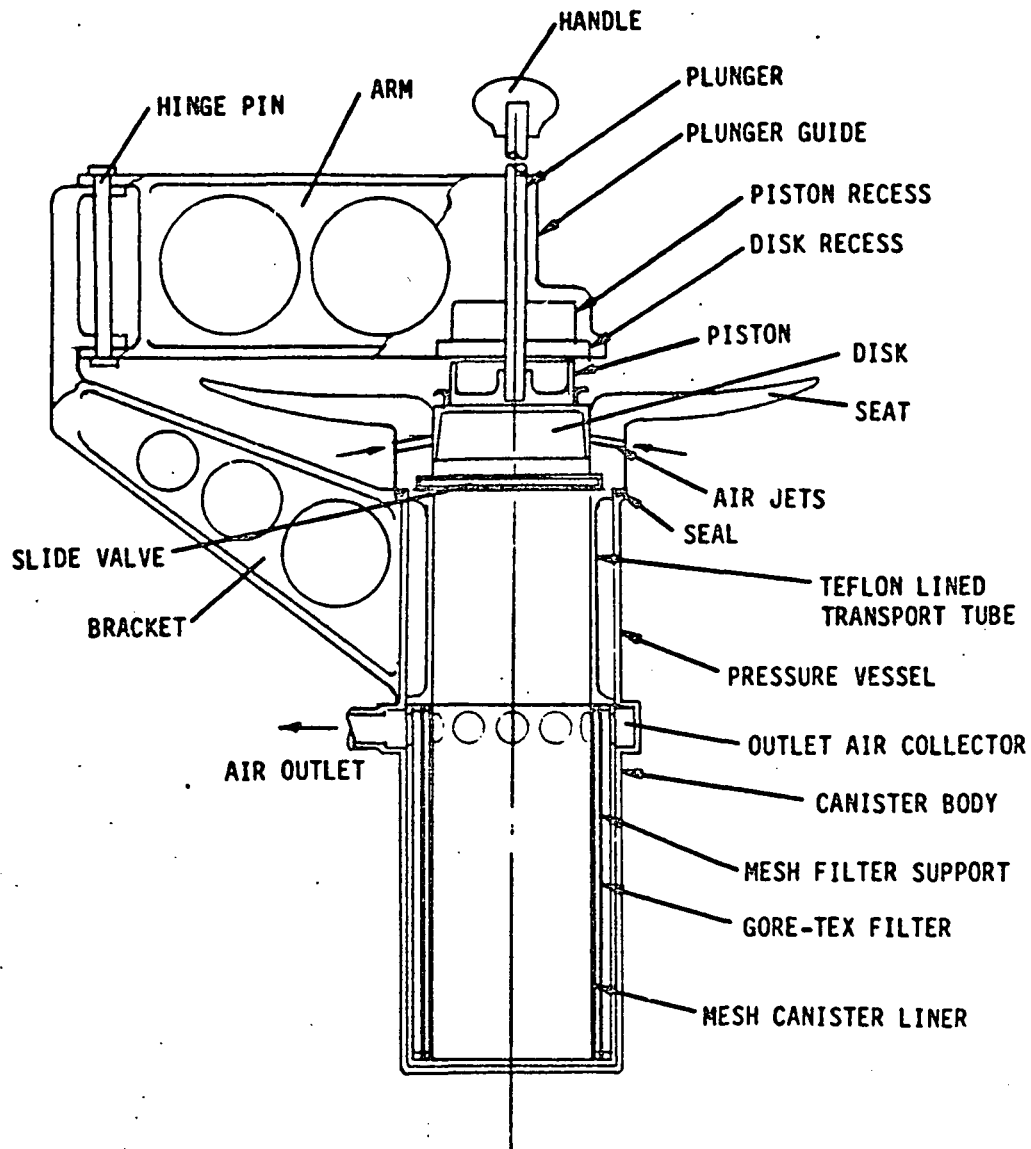


Figure 24
CANISTER COMMODE WITH COMPACTION DISKS

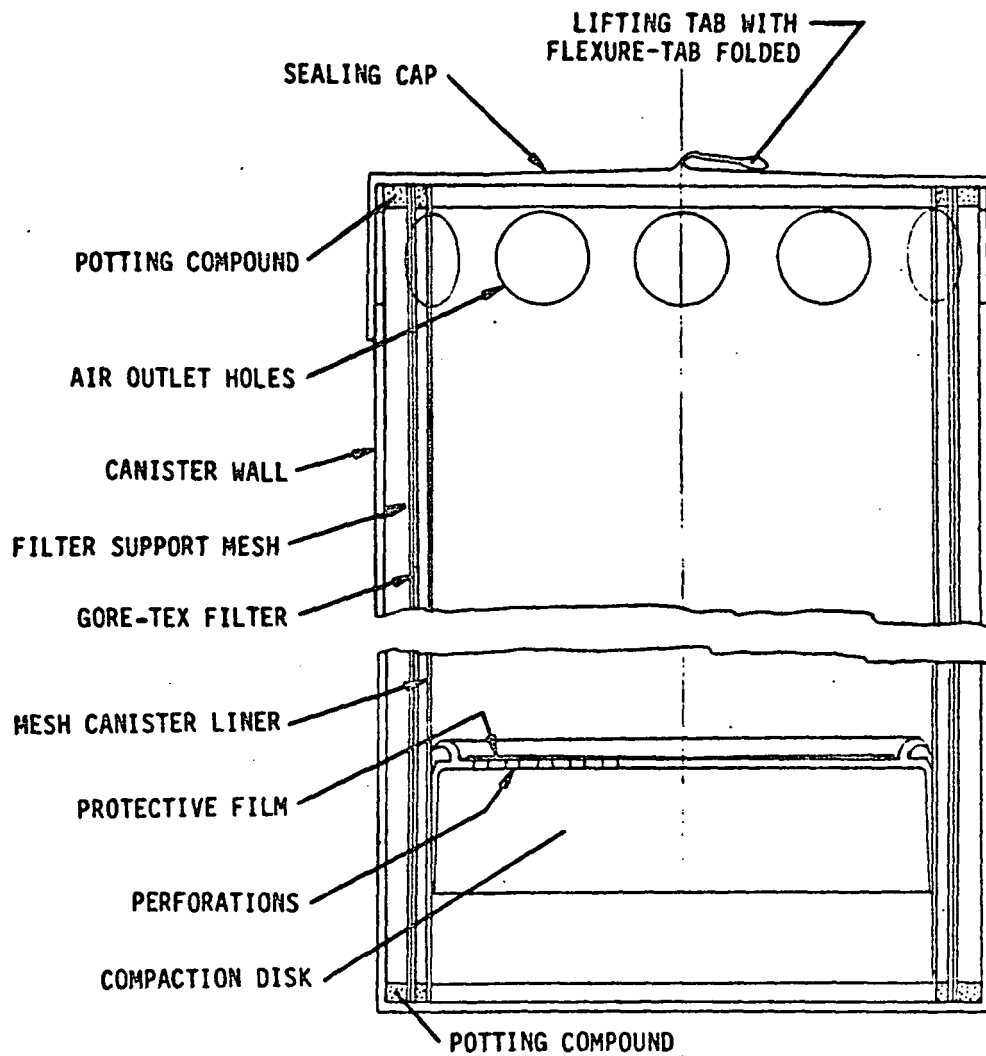


Figure 25
 COMMODE CANISTER WITH DISKS AND CLOSURE

Airflow from the canister is directed radially outward through the mesh above the last inserted disk and through the Gore-Tex hydrophobic, micropore, cloth-backed filter. This filter is supported on a second wire mesh screen of metal or plastic material. A radial distance of about 2.5 mm (0.10 inches) is assumed adequate to contain any debris that passes through the mesh and lodges against the filter. Only one loading of the canister is expected within the capacity of this filter. Air passing through the filter then turns axially upward through a 4 mm (0.15 in) passage along the solid wall of the canister, and is exhausted through a ring of 19 mm (.75 in) diameter holes near the top.

In this concept, the commode parts just under the slide valve by loosening latches at each side. Then the top of the commode is pulled straight up, and seat with slide valve lever, air jets, slide valve, and transport tube are removed as a unit. A lifting cap is pushed down the 127 mm (5 in) diameter by 229 mm (9 in) deep cavity and is pressed onto the top of the full canister. Then the folding tab on the lifting cap is grasped and the canister is pulled straight up and out of the commode. The elastomeric cap stays on by friction and seals the ring of holes around the canister. A fresh canister is slid down the hole and the commode top is pushed in behind it, the latches catching when in position, and the commode is again ready for use.

There are perforations in the central zone of the compaction disk to allow water vapor to escape when the commode is vented to vacuum. To prevent wastes from being extruded through them a thin film, with contract adhesive at the center to keep it in position, seals the perforations from the piston during compaction. Upon vacuum venting, the escaping vapor raises the thin film and departs by way of the entrainment airflow route.

Mounted to the main pressure vessel structure of the commode is a bracket which, by means of a hinge, permits a plunger arm to swing over the precise center of the transport tube and rest against a stop. This arm guides the compaction plunger with its piston down the transport tube and canister, and forces the compaction disk against the deposited wastes. The user first places a compaction disk, skirt down, into a recess in the plunger arm bottom. The piston pushes it along, guided by the shoulder on the disk. When the piston returns, the compaction disk remains in place upon the compacted wastes. Figure 26 is a tabulation of the steps taken in the compaction and removal operations. The piston and plunger never touch the transport tube or canister or any wastes and thereby remains sanitary. If gases are generated in storage, their pressure will enable them to escape between the overlapping skirts of successive compaction disks. The same applies to the lifting cap.

Figures 21 and 22 have been revised to show how space for storing empty and full canisters can be provided within the Shuttle commode space envelope. This arrangement applies to the disk canister as well as to the cup canister. The disk canister having the filter surrounding the wastes has 127 mm (5 in) diameter while the cup canister is just over 102 mm (4 in) diameter. In Figure 27, the dimensions of the three types of canister commode concepts are compared. Capacity of the disk canister exceeds that of the cup canister largely because the cup depth is not subtracted from the canister length. However, the transport tube length is no longer augmented by the cup depth. Experimentation is needed, in flight, to determine just what transport tube



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Compaction

1. Open slide valve
2. Deposit waste
3. Insert compaction disk in plunger arm recess
4. Depart from seat
5. Swing plunger arm over seat
6. Push plunger until it stops
7. Raise plunger
8. Swing plunger arm away
9. Close slide valve

Removal

1. Unlatch commode top
2. Lift top out of commode
3. Push canister sealing cap into place
4. Grasp tab on sealing cap and lift out canister
5. Insert fresh canister
6. Insert and latch commode top

Figure 26
DISK WASTE COMPACTION AND REMOVAL

	<u>Revolving Cup Canister</u>	<u>Stationary Cup Canister</u>	<u>Stationary Disk Canister</u>
Transport Tube Diameter	102 mm (4.00 in)	102 mm (4.00 in)	102 mm (4.00 in)
Transport Tube Length	229 mm (9.00 in)	219 mm (8.62 in)	219 mm (8.62 in)
Canister Length	427 mm (16.81 in)	456 mm (17.96 in)	456 mm (17.96 in)
Filled Length	313 mm (12.33 in)	332 mm (13.10 in)	450 mm (17.71 in)
Waste Volume	2538 ml (154.9 in ³)	2697 ml (164.6 in ³)	3648 ml (222.6 in ³)
Number of Canisters	7	9	9
Total Waste Volume	17,760 ml (1084 in ³)	24,270 ml (1481 in ³)	32,820 ml (2003 in ³)
Waste Volume (Feces, Paper Cups, or Disks)	186 ml/md (11.37 in ³ /md)	186 ml/md (11.37 in ³ /md)	166 ml/md (10.13 in ³ /md)
Capacity (man-days)	95	130	198
Capacity at 75%* Compaction (man-days)	71	98	148
Sealed Canister O.D.	105 mm (4.12 in)	105 mm (4.12 in)	127 mm (5.00 in)
Sealed Canister Volume	3670 ml (224 in ³)	3920 ml (239 in ³)	5780 ml (353 in ³)

* Actual percent compaction obtainable awaits test data.

Figure 27
COMPRESSION OF CANISTER DIMENSIONS



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length must be provided. Capacity of the stationary disk canister commode is estimated at 148 man-days on the same basis as before. A total capacity of 210 man-days may be within reach of this concept requiring no storage of wastes or of empty canisters outside the Shuttle commode space envelope, perhaps with slight bulging. A careful design study and tests would be needed.

5.1.5 Advancing Sleeve Commode

A novel type of commode design concept, illustrated in Figure 28, has been devised to promote compaction of wastes and ease of turn-around between flights, or to replenish its storage capacity during a flight. Within the same space envelope as the existing Space Shuttle commode there is a storage compartment for a folded sleeve, Figure 29, about 787 mm (31 inches in) circumference, a pair of rollers to flatten the waste matter within the sleeve, and a take-up reel. In use the sleeve becomes the container for feces and toilet paper or wipers. It is lined with a Gore-Tex hydrophobic PTFE filter material about a mil thick, supported on a light felt reinforcement and backed with a strong, open weave polyester scrim. Porosity of the sleeve is sufficient to permit the full $.85 \text{ m}^3/\text{min}$ (30 scfm) airflow to the fan separator to pass with about $.12 \text{ N/m}^2$ (5 in) H_2O pressure loss. This pressure loss balloons the sleeve outward against the inner walls of the commode and into contact with a standoff layer of wire mesh, which supports it, and permits the air to pass through the sleeve. The bolus of feces is entrained by air from the jets above the slide valve as in the existing Shuttle commode and is carried into the hollow of the sleeve. Air vents through the sleeve material and draws the waste solids into the pocket formed by the sleeve. Since the sleeve enters the chamber very close to the bottom of the slide valve, and is protected by the squeegee action of an elastomeric flap, no waste matter can enter the sleeve storage compartment. The distance from the bottom of the slide valve to the rollers at the bottom is about 304 mm (12 in), sufficient to enclose the longest dimension of any bolus. The hydrophobic filter layer has the advantage of containing any moisture from a wet discharge as with diarrhea, and it also has the advantage of keeping the interior of the commode clean to facilitate the changing of sleeves on the ground or in flight.

Upon completing the deposition of wastes in the sleeve, the crew member actuates a lever several times, by means of which a ratchet and pawl mechanism winds up the sleeve on a reel. In this way the strong scrim backing is able to transmit tension along the path of the sleeve and to draw lumps of feces between two spring loaded rollers with sufficient force to flatten them appreciably. Flattening permits the cross section of a deposit of feces to be reduced until moisture is readily able to diffuse away during exposure to overboard vacuum venting. Flattening compacts the wastes, reducing their radial thickness when stored on the reel, providing an efficient use of storage volume. Tension in the sleeve is produced by the drag of the sleeve pressed against the standoff mesh, and is augmented by a brake on one of the large diameter rollers. Tension compacts the wastes and the sleeve material upon the reel, and with every revolution the compaction force on the inner turns increases. As the waste matter disappears beyond the rollers, fresh sleeve surface is drawn from the storage compartment and restores the interior

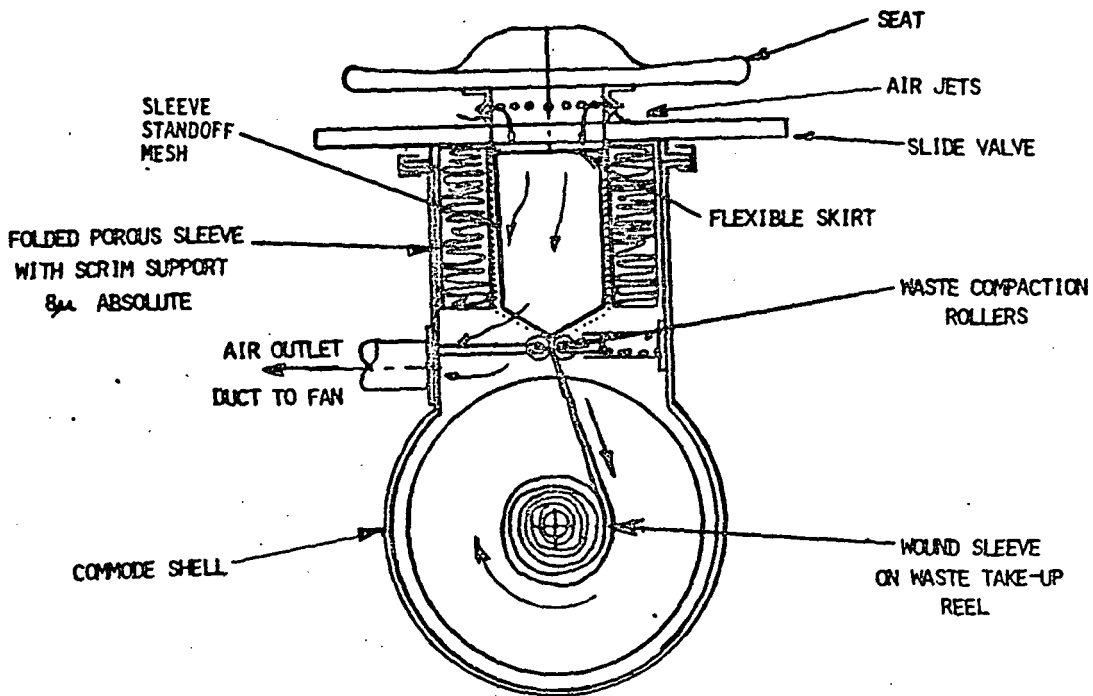


Figure 28
ADVANCING SLEEVE COMMUNE

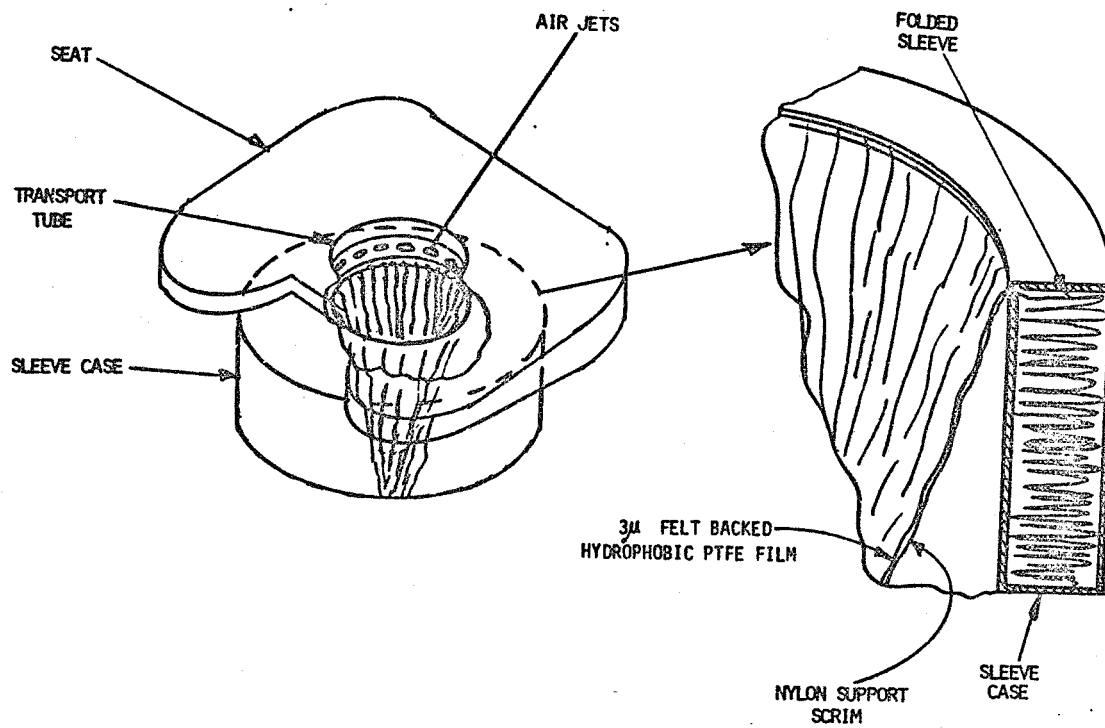


Figure 29
SLEEVE CONSTRUCTION



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of the commode beneath the slide valve to a clean condition. By printing the sleeve a contrasting color in bands of about 304 mm (12 in) the user may operate the reel until the color has reversed, and a clean expanse of sleeve is in place. A third color warns of the approaching end of the sleeve. This approach may be recognized as similar to the way film was handled in old time cameras, which was quite workable.

Sleeving circumference is governed by the storage compartment size, namely its outside diameter. Thus a comparatively small outside diameter and a fairly long length are desirable. Outside diameter in turn is governed by the inside diameter of the cavity required for accepting wastes. The 102 mm (4 in) diameter of the Space Shuttle transport tube has been retained. As the sleeve reaches the rollers its width, which would be 394 mm (15.5 in) if spread flat, increases so that many of the longitudinal wrinkles stretch out laterally. The sleeve is guided at the two sides by large radius contours on the housing wall, and fans out to fill the width of the reel. In operation the flattened deposits within the sleeve will tend to accumulate near the center to a width approximating that of the rollers, or about 228 mm (9 inches). At each side the bulk of the sleeve material will tend to diverge and to fill the less tightly bound region, out to about 279 mm (11 in) total width.

When the sleeve has been advanced, the crew member closes the slide valve thereby turning off the fan separator. He opens the overboard vacuum vent valve, and moisture from the feces diffuses out through its large flattened surface and through the porous sleeve. For strength with light weight, and particularly for rigidity of sealing surfaces, the housing cross sections have been made circular wherever possible. All the fan separator and vacuum venting components, and the method of operation remain unchanged from the existing Space Shuttle commode. On the outside there are differences, the major one being that the seat has been moved forward 152 mm (6 in). That requires the crew member's knees to be bent at a sharper angle, but without notable inconvenience. The two front hand-holds are repositioned somewhat to allow for the contours of the advancing sleeve commode.

When the sleeve runs out or the reel binds because of a full loading, the sleeve can be replaced in flight. Ordinarily this will not occur because it has been sized for a 52.5 man-day capacity. Three spare sleeves and reels will suffice for the maximum 210 man-day mission capacity. Packing density on the reel is 43%. This high density is obtained by winding the sleeve on the reel under tension after flattening between the rollers. It must of course be verified by test. Sleeve tension is applied as force to the wound sleeve in the same way as belt tension is applied as force to a pulley. Since this tension is applied individually to each revolution of the sleeve upon the reel, the wastes at the inner turns must support an ever increasing compression load which serves to compact them and to retain that compaction. Total storage volume required for 210 man-days is .078 m³ (2.75 ft³), with 3 loaded reels in rectangular array.

Replacement of the sleeve is accomplished by first releasing a bar that binds the reel if sleeve and contents have reached the maximum allowable diameter. Then any remaining sleeve is wound onto the reel. Two spring loaded latches

are released and a round cover on the bottom front of the commode is lifted off from a bonded ring seal, carrying with it the outer bearing of the reel shaft. The end of the reel shaft is grasped and the whole reel is withdrawn from the commode and is inserted into a plastic bag to be twist-tied for separate storage and ultimate disposal. Two other spring loaded latches are released, permitting the top of the commode to be lifted off, exposing a bonded ring seal and the storage cavity for a fresh, folded sleeve. A sleeve is removed from its carrying container, a flexible plastic wrapper, and is inserted into the storage cavity. The end of the sleeve is thereupon pulled out and pushed down through the central chamber of the commode and inserted between the rollers, which are advanced by means of the actuating lever until about a foot of length is inside the reel compartment. A new reel is inserted, the end of its shaft entering the bearing on the far wall, and the molded teeth on its flange engaging the ratchet and pawl driving and locking mechanism. The end of the sleeve is then tucked into a slot in the 51 mm (2 in) diameter axle of the reel and holding the outer end of the reel shaft in one hand the advancing lever is actuated with the other to take a full turn, binding the sleeve to the reel. Next, the outer flange is threaded onto the reel shaft, and the cover is replaced joining the bearing to the shaft. Finally the top cover with the seat is replaced, closing its two latches, and the commode is again ready for use. This reel replacement procedure could be performed nearly as easily in weightlessness as on the ground, and should not be objectionable because of the always clean interior insured by the hydrophobic film filter layer in the sleeve. Sleeve waste compaction and removal steps are itemized on Figure 30. Figures 31-33 show views from drawing SVSK 111101 of the advancing sleeve commode, with details drawn to scale.

5.1.6 Compaction Tradeoff Comparison

Three basic configurations comprising five detailed configurations for alternative improved Shuttle commodes, offering improved waste compaction and quick cost-free turnaround, can now be compared. In the first place cost of turnaround is actually the cost of replacement containers for wastes. These involve a bag, a canister or a sleeve in which a Gore-Tex hydrophobic fabric reinforced filter is an element. Bacteria are controlled by this means, as well as the motion of any liquid moisture, while the entrainment air is passed on without excessive pressure loss. Actual cost of these containment materials will vary widely with the quantities procured and the specification requirements that may be imposed. It is suggested that care be taken to avoid unnecessary requirements that could sharply increase costs. In any event an expense of \$2.00 to \$10.00 per man-day is expected for replacement materials. The cost of labor is that of the crew member's time. In Figure 34 the time estimated for removal of compacted wastes and replacement of containers is tabulated for each concept. These times are only a few minutes each.

Compaction densities of waste feces and paper are compared in Figure 35. Density is reckoned as percent of full compaction with complete elimination of air filled voids. Values are given for density of compaction within the compaction device, and again for density based upon the space required outside the commode for an extended mission. There is not a wide variation among them, but the stationary disk canister concept is superior. Volume in excess

COMPACTION

1. OPEN SLIDE VALVE
2. DEPOSIT WASTE
3. OPERATE RATCHET LEVER

REMOVAL

1. OPEN FRONT DOOR
2. PULL OUT REEL
3. INSERT IN SMALL BAG
4. TWIST TIE
5. DEPOSIT IN WASTE BIN
6. OPEN TOP DOOR
7. INSERT FOLDED SLEEVE
8. INSERT NEW REEL
9. THREAD SLEEVE
10. FASTEN REEL FLANGE
11. CLOSE DOORS

Figure 30
SLEEVE WASTE COMPACTION AND REMOVAL

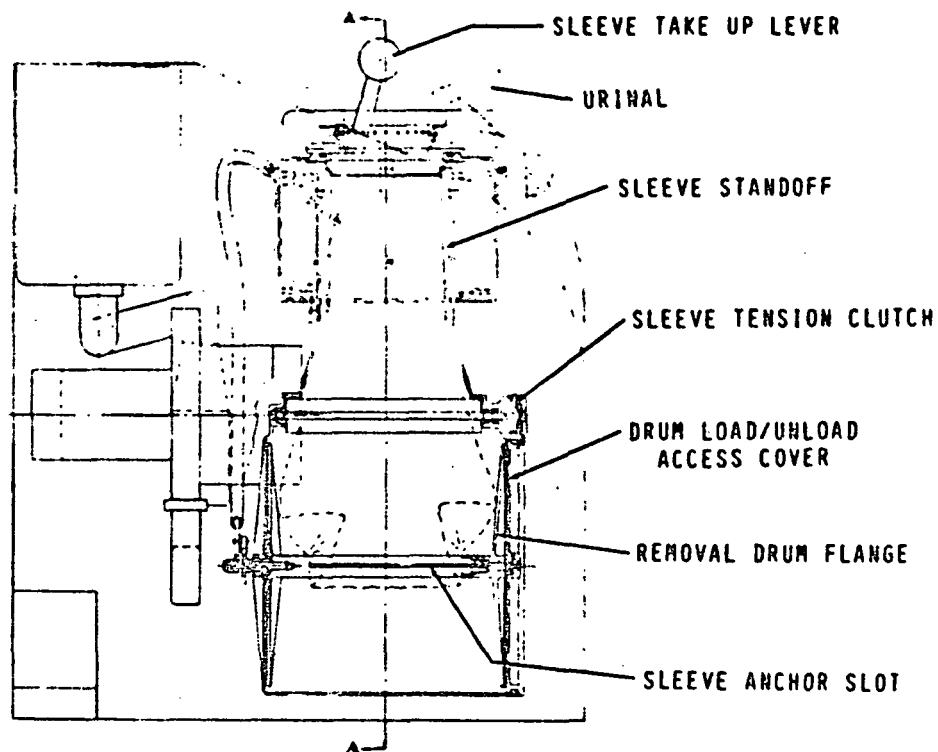


Figure 31
ADVANCING SLEEVE COMMODE SIDE VIEW

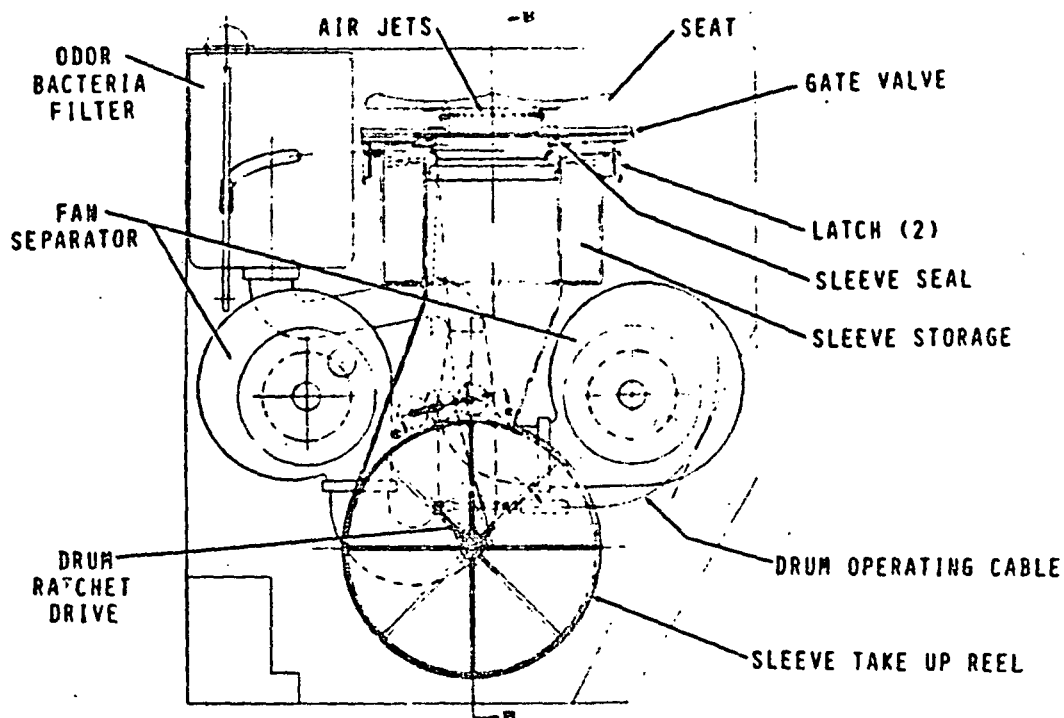


Figure 32
ADVANCING SLEEVE COMMODE FRONT VIEW



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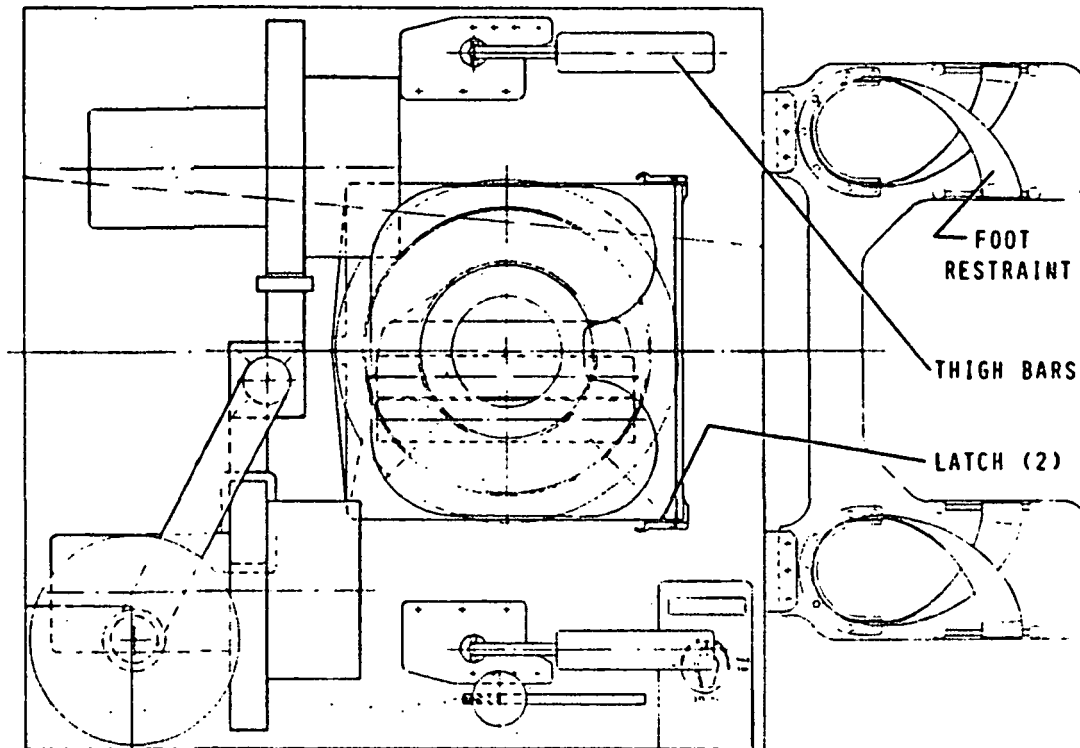


Figure 33
ADVANCING SLEEVE COMMODE TOP VIEW



TIME TO REMOVE COMPACTED WASTES AND TO REPLACE CONTAINER (MIN)

FRONT DOOR	3.8
REVOLVING CUP CANISTER	8.8
STATIONARY CUP CANISTER	1.5
STATIONARY DISK CANISTER	1.5
SLEEVE	4.5

Figure 34
TURNAROUND TIME



	<u>PERCENT</u>
<u>THREE-LAYER BAG</u>	
IN USE	12
COMPACTED (50% VOID)	41
<u>CUP CANISTER</u>	
IN CANISTER	55
IN RECTANGULAR ARRAY	40
<u>DISK CANISTER</u>	
IN CANISTER	74
IN RECTANGULAR ARRAY	47
<u>ADVANCING SLEEVE</u>	
ON REEL	43
IN RECTANGULAR ARRAY	34

Figure 35
COMPACTION DENSITY OF FECES AND PAPER



of the space envelope for short and long duration missions appears in Figure 36. There it is to be noted that each concept contains all wastes within the Shuttle commode space envelope for at least 52.5 man-days capacity. For 210 man-days each has some external storage volume required. If compaction density for disk storage could be increased from 75% assumed to something approaching 100% its volume requirement would decrease from .023 m³ (0.8 ft³) to perhaps a negligible magnitude. That might require a minor bulge on the commode contours to accommodate.

In Figure 37 weights are compared. Weights for 210 man-days are higher, reflecting the need for stored containment supplies. The stationary disk concept and the stationary cup concept excel and are about equivalent. They are competitive with the three-layer bag concept.

A comparison of features is reviewed in Figure 38. Here we see the array of factors in the waste collection subsystem identified for the various concepts. Treatment in each case for the Shuttle is by overboard venting, and entrainment is by air as in the existing Shuttle commode.

Tradeoff criteria are defined in Appendix A, as absolute, primary and secondary. In the dissertation that follows the various commode concepts will be considered relative to these criteria in order to arrive at a selection of an optimum concept.

As tabulated in Figure 39, each of the five concepts meets the absolute criterion of performance with a satisfactory rating because each is fully capable of functioning as a commode in weightlessness, as demonstrated on Space Shuttle flights, and in addition provides for compaction of wastes and means of waste container removal and replacement in flight with minimal storage volume. For safety, none of the five generates a known hazard in any phase of use, servicing, or storage. Availability in fully developed form by the year 1987 is easily in reach for all five concepts, although there is a variation among them, the front door being by far the most readily available.

Among primary criteria, the first is crew acceptability. A rating of excellent must be tempered by recognition of the mere fact of weightlessness when the crew is accustomed to the convenience of gravity. The ideal must be in space, rather than on the ground. Except for the bag concept each has been rated excellent because feces and paper are out of sight within the commode. The front door concept has been marked down to very good because sight of wastes may be obtained at some distance within when the slide valve is opened for use.

There is no difference in containment as will be discussed under the contamination criterion, but there is a further consideration. With the front door, the servicing operation involves handling a bag known but not felt to be containing wastes. With the canister concepts wastes are in a solid cylinder while being handled, thus conceivably arousing less objection. Servicing of the advancing sleeve involves handling a reel heavily wound with sleeving and thereby somewhat between the other two esthetically. These further considerations tend to reinforce the judgements on crew acceptability.

VOLUME IN EXCESS OF SPACE ENVELOPE

	<u>52.5 MAN-DAYS</u>	<u>210 MAN-DAYS</u>
FRONT DOOR	0	.062 m ³ (2.2 FT ³)
REVOLVING CUP	0	.051 m ³ (1.8 FT ³)
STATIONARY CUP	0	.042 m ³ (1.5 FT ³)
STATIONARY DISK	0	.023 m ³ (0.8 FT ³)
SLEEVE	0	.079 m ³ (2.8 FT ³)

Figure 36
STORAGE VOLUME

ESTIMATED WEIGHT OF COMMODE AND SUPPLIES (LB)

	<u>52.5 MAN-DAYS</u>	<u>210 MAN-DAYS</u>
FRONT DOOR	49.4 KG (109 LB)	50.8 KG (112 LB)
REVOLVING CUP	54.9 KG (121 LB)	60.3 KG (133 LB)
STATIONARY CUP	44.0 KG (97 LB)	49.4 KG (109 LB)
STATIONARY DISK	44.9 KG (99 LB)	47.2 KG (104 LB)
SLEEVE	55.8 KG (123 LB)	70.7 KG (156 LB)

Figure 37
WEIGHT

<u>TITLE</u>	<u>ENTRAINMENT</u>	<u>COLLECTION</u>	<u>TREATMENT</u>	<u>COMPACTION</u>	<u>TRANSFER</u>	<u>STORAGE</u>
BAG	AIR	BAG	VACUUM VENT	BAG COLLAPSE	PLASTIC BAG	COMPARTMENT
CUP	AIR	CUP	VACUUM VENT	CUP STACKING	CANISTER	COMPARTMENT
DISK	AIR	CANISTER	VACUUM VENT	DISK COMPRESSION	CANISTER	COMPARTMENT
SLEEVE	AIR	SLEEVE	VACUUM VENT	ROLLING & WINDING	REEL	COMPARTMENT

Figure 38
COMPARISON OF FEATURES

CODE

5 EXCELLENT
4 VERY GOOD
3 GOOD
2 FAIR
1 POOR

	CONCEPT	FRONT DOOR & BAG	REVOLVING CUP CANISTER	STATIONARY CUP CANISTER	STATIONARY DISK CANISTER	ADVANCING SLEEVE	EXISTING NON-SLINGER BAG
ABSOLUTE	PERFORMANCE	S	S	S	S	S	U
S = SATISFACTORY	SAFETY	S	S	S	S	S	S
U = UNSATISFACTORY	AVAILABILITY	S	S	S	S	S	S
PRIMARY	CREW ACCEPTABILITY	4	5	5	5	5	4
	PAPER DISPOSAL	5	5	5	5	5	5
	NOISE	4	4	4	4	4	4
	CONTAMINATION	5	5	5	5	5	5
	RELIABILITY	5	4	5	5	4	5
	SCORE	23	23	24	24	23	23
SECONDARY	RETROFITABILITY	5	3	4	4	3	5
	GROWTH POTENTIAL	5	5	5	5	5	1
	POWER	5	5	5	5	5	5
	VOLUME COMPACTION	5	4	4	5	5	3
	WEIGHT	4	4	5	5	3	5
	COST TO USE	5	5	5	5	4	5
	SERVICING TURNAROUND	5	5	5	5	3	1
	EASE OF OPERATION	5	4	4	5	4	5
	SCORE	39	35	37	39	32	30

Figure 39
TRADEOFF - COMPACTION AND TURNAROUND



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Each concept accepts paper wipers as readily as it accepts feces, and each is rated excellent in this regard. There is no need for separate disposal means.

None of these concepts adds noise in the form of motor-driven machinery or air flows in excess of that in the existing Space Shuttle commode. Noise is consequently significantly reduced by eliminating that caused by the operation of the slinger in the earlier Space Shuttle commode. Nevertheless, since operation of the fan separator remains essential, each is rated very good, rather than excellent.

Contamination is a criterion defined as the unlikelihood of contaminating the surroundings. Each is uniformly rated excellent. The only question would be after the failure of a fan separator while in use. Since there is no slinger and no acceleration of the vehicle, no force would exist for causing wastes to float out of the commode before the auxiliary fan separator was started. Both the cup and sleeve commodes maintain positive containment for all but the waste immediately deposited, and the same remark applies. Each is rated excellent on this criterion.

Reliability is an estimate of relative simplicity and maintainability. In this respect, the front door commode is by far the simplest. It is also thereby the easiest to maintain free of mechanical defect, and is rated excellent. Both the revolving cup canister and advancing sleeve exhibit considerably more complexity but in the form of well developed hardware should be inherently reliable and are rated very good. The stationary cup canister and stationary disk canister concepts are simple and do not require mechanisms that would be hard to reach or repair, and have been rated excellent.

When the scores are added for the five concepts, a tie is obtained among the front door, revolving cup canister, and advancing sleeve concepts, while the other two, the stationary cup canister and stationary disk canister are rated a point higher. These are close ratings and need the secondary criteria to break the tie. The first of these is retrofitability to the Space Shuttle. Here the front door concept is rated excellent because it fits within the existing configuration with a need only for cutting away part of the housing. The revolving cup canister and advancing sleeve are rated good in comparison because the basic structure of the commode is new, and the seat is moved, although most auxiliary components remain in the original places and the space envelope is not violated. Both stationary cup and stationary disk canister commodes rate very good because externally there is no change.

Growth potential for all concepts is excellent, in that the feasibility for longer missions is not limited. As long as supplies are provided, and wastes are removed for storage or disposal, use may be continued indefinitely.

Power is rated excellent for each since none demands any new use of power nor requires any increase of fan power because of increased pressure loss or for other reason.



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Volume of compaction is of significance for storage of wastes in a 210 man-day mission since the space envelope is maintained for all concepts. In this regard, soft waste containers occupy less volume in storage than rigid waste containers because they adapt to the shape of storage space available. Rigid waste containers are assumed to be stored in rectangular compartments, and their round cross sections are thereby the cause of a loss in storage packing density. The assigned ratings are as follows: front door, very good; revolving cup canister, very good; advancing sleeve, good; stationary cup canister, very good; stationary disk canister, excellent.

Weight has been rated as very good for the front door as it involves about a five pound increment over the weight of the existing Space Shuttle commode, and is probably lighter than the original Space Shuttle commode with a sling-er. Both the revolving cup canister and advancing sleeve concepts are significantly heavier, with weight increments calculated at approximately twenty pounds each or about eighteen percent more than the weight of the existing Space Shuttle commode. On this basis, each is given a rating of very good. Stationary cup and stationary disk canisters are notably lighter because of their smaller pressure vessel size, and are rated excellent.

Cost is the relative cost to use the commode concept under consideration. This cost is essentially that of replacement containers for waste that must be discarded with the wastes. Although each is quite different in its own way and the relative costs vary, none is excessively high. Cost comparison at this stage is necessarily crude and has resulted in the following ratings: front door, excellent; revolving cup, excellent; advancing sleeve, very good; stationary cup, excellent; and stationary disk, excellent. The large amount of material used per man-day for the advancing sleeve was considered a reason for reducing its score.

Servicing as a criterion is defined as ease of emptying the wastes and re-charging the commode with such supplies as it needs to continue in operation. The front door concept receives an excellent rating because a few very simple steps taking only a few minutes effort are sufficient to compact the wastes, dispose of them, and replace the three-layer bag. In contrast, the revolving cup canister requires several repeated operations to remove, store and replace individual canisters, taking about as long with each and requiring at least as much care. On this basis, it is rated very good. For the advancing sleeve, the crew member must carry out several different operations, each only about as complex as the operation on the front door. These are the winding up, removal, and bagging of the loaded reel, and the installation, threading, and connection of the new sleeve and reel. For this reason, it is rated lower than the revolving cup canister, as good. Both stationary cup and stationary disk rate excellent because of cleanliness and ease.

Scores from the secondary criteria ratings are intended to break the ties from primary criteria ratings and to make a final selection. Relative scores in the secondary criteria ratings are indicative of relative merit. Totaling these scores, we have obtained a high score of 39 for the stationary disk concept and a somewhat lesser score of 37 for the stationary cup.



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Since both stationary cup and stationary disk concepts rated higher than the others on the primary criteria, they should be considered as the real contenders for the secondary criteria. The score of 39 earned by the front door commode is equivalent, but its primary criterion score was less and should make it ineligible. These ratings are so close that an obvious selection cannot be made with only a small amount of effort. In summary, the stationary disk concept has been selected in view not only of its tradeoff ratings, but in consideration of the practical aspects of the various competing concepts as well.

High density mechanical compaction involving many atmospheres of pressure may be posed as an ideal in which 100% compaction is attained. Figure 40 is provided to list the factors which prevent this approach to an ideal from being taken in this study. Other uncompetitive concepts evaluated in this study but rejected on absolute criteria are presented in Appendix B.

5.2 Concepts For Non-Venting Waste Treatment

Three concepts are to be discussed. These are (1) microwave drying in which the commode becomes a microwave oven and moisture is condensed in a circulating air loop; (2) thermoelectric refrigeration to maintain wastes inactive while the commode is a refrigerator; and (3) biodegradation of wastes in the commode permitting bacteria to generate their own inhibitors.

Certain observations are in order to compare these three concepts. For example thermoelectric refrigeration is at a nominal 1°C (34°F) temperature where bacteria remain active at a low level. Microwave drying is capable of thorough drying from heat generated at the interior of the wastes, and would effectively stop bacterial metabolism. Biodegradation lets bacteria slowly inactivate themselves by generating their own inhibiting substances. The same can be expected with refrigeration, but over a much extended time. Refrigeration of course requires constant power, at a low rate, while microwave drying requires substantial power for a short period, perhaps at off-peak intervals, and biodegradation requires no power. Odor generation effectively stops with the cessation of the metabolic activity in each case. Space Station weight penalties for power are severe, and the possibilities for off-peak microwave usage should be investigated. Thermoelectric power is continuous and should be minimized. Cabin atmosphere loads associated with these treatment concepts, and sterilization by incineration as well, are listed in Figure 41.

Non-Venting Waste Treatment - In the Space Shuttle wastes are treated by exposure to overboard vacuum venting. This produces a drying of feces that are collected in the commode separately from urine or other sources of water. Drying inactivates the bacteria in feces preventing them from metabolizing and generating gases. In the Space Station overboard venting is not desired as a means of waste treatment because of possible condensation effects on scientific instruments. Early in the Space Station program overboard venting might be permissible allowing the Space Shuttle waste collection subsystem to be used. Later, non-venting is a likely requirement and other means of treatment must be defined. The basic principle to be maintained is to collect and store fecal wastes and paper in a sanitary and odorless manner, requiring no manual

- REQUIRES SELF-CLEANING FILTER
- REQUIRES POWER FOR FILTER CLEANING
- REQUIRES POWER FOR COMPACTION
- HIGH COMPLEXITY

BEYOND SHUTTLE NEEDS

SPACE STATION TO COMPACT ALL TRASH

- UNSATISFACTORY AVAILABILITY

Figure 40
HIGH DENSITY MECHANICAL COMPACTION

- DRYING

ADDS 5% TO H₂O REMOVAL

- REFRIGERATION

NEGLECTIBLE EFFECT AT 1°C (34°F)

- BIODEGRADATION

ADDS 0.2% TO CO₂ REMOVAL

ADDS NEGLECTIBLE CH₄

- STERILIZATION

INCINERATION ADDS 4% CO₂ & 6% H₂O

Figure 41
CABIN ATMOSPHERE LOADS

handling of wastes in use, and preferably none at ultimate disposal. Sanitation is provided by containing the bacteria that comprise about 40% of the mass of feces separately from the cabin environment. Odors are controlled by maintaining an inward airflow into the commode whenever it is open, which also prevents the escape of any bacteria suspended in the air. Charcoal filtration and filtration by other absorbents trap odors before the air is returned to the cabin by the fan or through any vent. A bacterial filter prevents bacteria from escaping by this route thereby completing the dictates of sanitation. When the commode or any vent. A bacterial filter prevents bacteria from escaping by this route thereby completing the dictates of sanitation. When the commode or any waste storage compartment is closed it must be sealed to resist the escape of odors or bacteria. Sanitation and odor control are provided by a suitable waste collection system. Waste treatment without venting can be provided by several means. These include drying, refrigeration, biodegradation and sterilization. Several concepts have been devised for possible application to Space Station making use of a satisfactory waste collection system applicable to the Space Shuttle.

Drying - Bacteria are inactivated by drying and maintaining the condition of dryness. When they are given sufficient moisture at a moderate temperature some fraction, which varies widely with conditions, will return to normal activity. In the Space Station the feces can be stored in a desiccated condition at atmospheric humidity for an indefinite period with the bacteria inactive. There is little likelihood of inadvertant moistening.

Refrigeration - Bacteria are inactivated by maintaining them at a low temperature. At 0°C (32°F) their activity is low, while at -18°C (0°F) it is much lower. Although bacteria active at room temperature may become inactive at low temperatures, there are other bacteria that are active at low temperatures. Their activity rates tend to be low but they do not stop until very low temperatures are reached. In the Space Station the feces can be stored in a refrigerated condition with the bacteria essentially inactive. Continuous power is required to maintain the low temperature, and at 0°C (32°F) the power level is relatively small, but at -18°C (0°F) it becomes quite significant. Any interruption of power supply or fault in the refrigeration equipment will restore the bacteria to normal activity.

Biodegradation - Bacteria in feces tend to digest the nutrients until they are consumed and thereupon to continue by digesting one another until conceivably all carbon is gone, with only inorganics remaining. In actuality the degree to which the various processes involved are carried out varies widely with conditions of temperature, amount of moisture present, types of bacteria, types of nutrients, access to air, and time. There can be a recovery of gas generation after the bacteria adapt to new conditions, a population minority becoming dominant after an original majority becomes inhibited. Experiments in 1962 by Wheaton, et al on the storage of feces at 30°C (86°F) demonstrated a production primarily of CO₂ and CH₄. Minute amounts of H₂ and H₂S were sometimes produced. Organic odors in trace amounts can escape before they are digested. Feces, unwetted by urine or other moisture were found to generate a relatively small amount of CO₂, a maximum of about 0.015 kg/kg (0.015 lb per lb) of feces, taking about 8 days to reach 95% of that level. A much smaller

amount of CH_4 , a maximum of 0.0005 kg/kg (0.0005 lb per lb) of feces was generated, taking about 3 days to reach 95% of that level. Action is thought to be inhibited by the concentration of acids in their slight water content, although the pH of moisture found in feces varies widely above and below the neutral. Feces stored in this condition, that of naturally occurring inhibition may be termed to have undergone a process of biodegradation. They have been observed to remain without evident change over a period of years thereafter. In the Space Station there is little likelihood of inadvertent moistening that would reactivate the bacteria.

Sterilization - Bacteria in feces may be killed outright by mixing with suitable biocides for the various bacteria present. Unless very strong or corrosive poisons are used, the right biocide for each type of bacteria must be found. Sterilization may also be accomplished by incineration of the whole mass of feces, or by X-ray radiation of a sufficient dose. Sterilization is permanent inactivation until such time as the feces may be infected with live bacteria from the environment, or possibly when biocides are diluted.

Cabin Atmosphere Loads - Calculation of loads added to the cabin air revitalization equipment by the various methods of non-venting treatment are summarized in Figure 41. There it is seen that none of the methods is a serious penalty to the equipment designed for respiratory loads of CO_2 and moisture removal. Drying feces adds 5% moisture if it reached the cabin air. A closed loop drying system separates fecal moisture from the cabin loop in all the drying concepts presented in this study. This has been done to avoid the possible rejection of the concept on esthetic grounds, since atmospheric condensate is intended for recycling into potable water.

Waste Treatment Summary -

Drying by microwave heating drives off fecal moisture which can be purified as humid air by passing through charcoal, Purafil and a bacteria filter. The cabin air moisture removal load would thereby be increased 5%.

Refrigeration to 0°C (32°F) by thermoelectric cooling using 45°F chilled water. Heat sink puts essentially nothing into the cabin atmosphere, but the refrigeration load is constant.

Biodegradation if at 30°C (86°F) adds a maximum of 0.18% to cabin air CO_2 removal load and a negligible amount of CH_4 .

Sterilization whether by biocide slurry, incineration or X-ray introduces complexity and hazards.

Waste Treatment Concepts - Three concepts were found competitive after preliminary study. They have been explored in more detail and are discussed in the following section. They are microwave drying, thermoelectric refrigeration and biodegradation.

5.2.1 Microwave Drying

Drying of feces by microwave heating can be accomplished readily in the bag, canister or sleeve commodes evaluated for Space Shuttle application. In each of these applications conventional microwave oven components are used, the active element being the magnetron microwave radiation generator. The commode itself takes the place of the conventional oven, and is connected to the magnetron by a wave guide. Microwave shielding is provided for the commode as for an oven, with the slide valve providing a metallic closure and duct openings covered with metal screen. Metallic labyrinth closures are provided as with conventional microwave ovens, and an electrical interlock interrupts power to the magnetron when the slide valve opens. A closed air circuit is used for the drying cycle, incorporating a regenerator, condenser, fan separator and wastewater accumulator. Venting of the circuit to equalize pressures is through a small restriction to a point upstream of the bacteria and odor filter that forms a part of the air entrainment system as in the Shuttle commode.

Figure 42 is a schematic diagram of a microwave drying system shown in conjunction with a front door, 3-layer bag commode. Other than for the closed loop drying circuit and its vent line this schematic corresponds with that used in the Shuttle. Since overboard venting is not desired, valves and lines for that purpose have been deleted. A fan separator in the drying circuit draws air from the closed commode, through the heat conserving regenerator to a condenser cooled by the chilled water facility. Moisture evaporated from feces by microwave heating in the commode is condensed in the condenser. Condensed water drops are swept along by the air flow maintained at a high velocity to overcome their functional resistance. Velocity is kept high for the short distance to the fan separator where the water is centrifuged from the air and pumped via a check valve to the wastewater accumulator. The air returns to the commode by way of the magnetron, providing its necessary cooling, and gaining heat that together with the heat gained in the regenerator carries away the water vapor generated by microwave heating of the feces. The exterior of the commode and all the ducts and components of the closed loop drying circuit must be insulated to prevent condensation of moisture between the heated wastes and the condenser, and to conserve circuit input energy between the condenser and the commode. This drying circuit is made a closed loop in order that wastewater from feces be stored separately from cabin atmospheric condensate which, together with urine, is intended for reclamation.

Advantages of Microwave Drying - Thorough drying of fecal matter leaves it in a condition that will not change with time until moisture is added. There is little likelihood of moisture being added accidentally, and no further attention is required. Containment by reasonable means to prevent gross contamination of the surroundings remains necessary for sanitation, and the containment means should therefore be reasonably durable. Sanitation is provided in a health degree at far lower odors of cleanliness than is required for toxic substances, or when working to clean room standards, and is thereby much more easily attained.

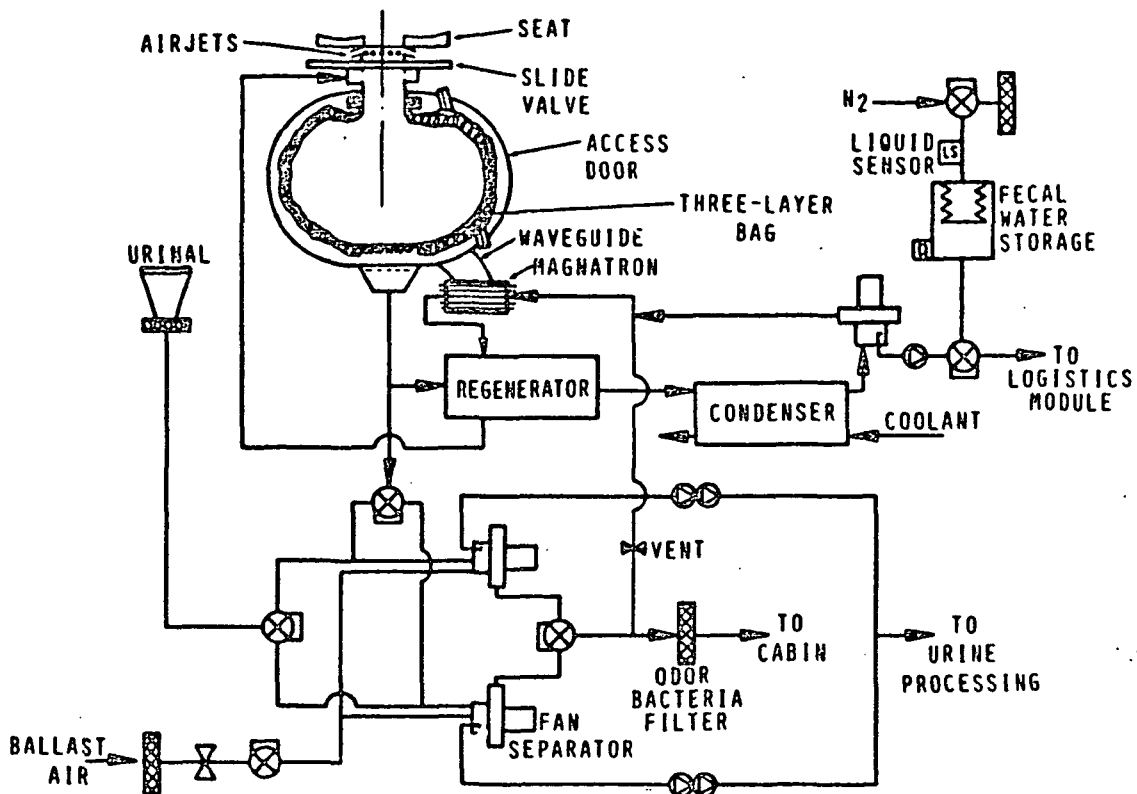


Figure 42
MICROWAVE DRYING AT CABIN PRESSURE

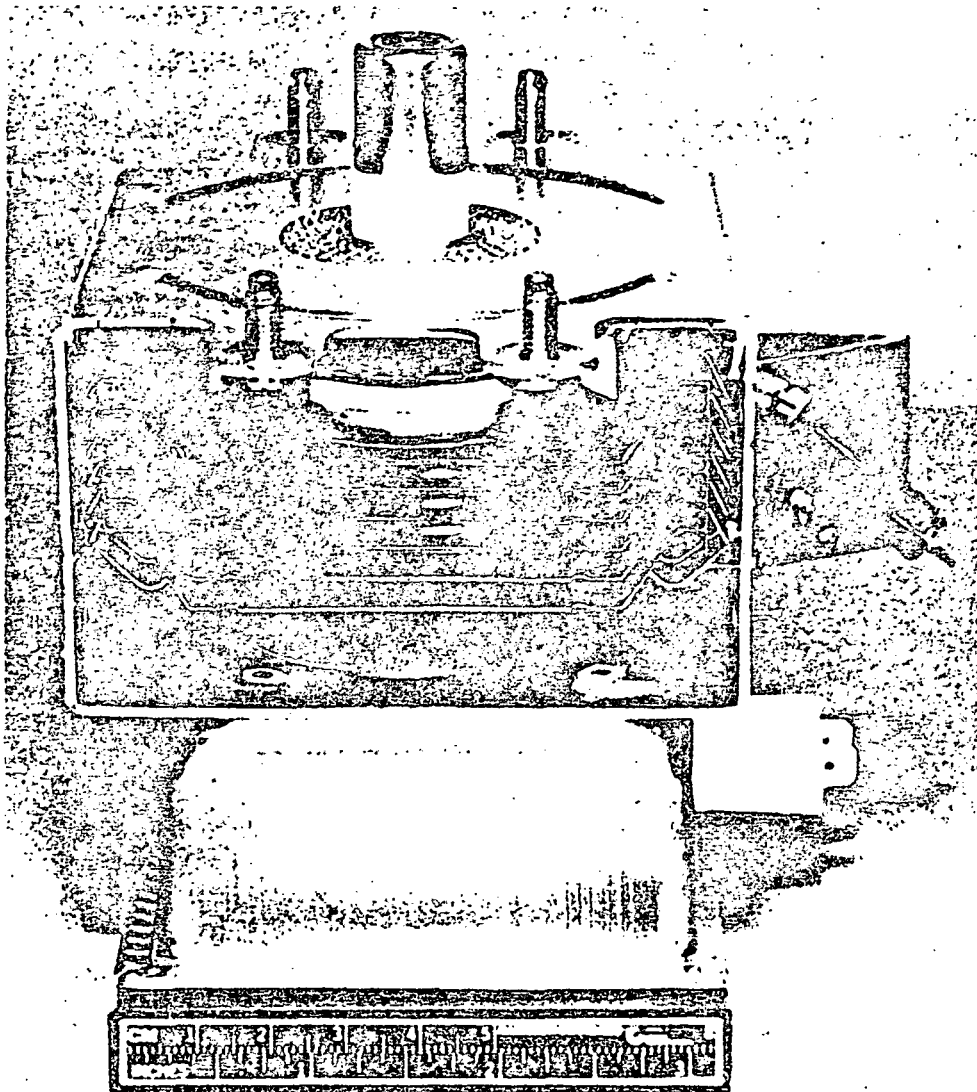


In the Space Station weight penalty for electric power is based on the peak load, since energy storage is not normally available. Since microwave drying is not time dependent it could be governed to operate only when the power supply system is off peak by the amount of the microwave demand. In this way its weight penalty may be minimized.

Microwave drying is not cooking in the sense that cooking kills bacteria. Killing bacteria by cooking requires sufficient time at elevated temperature. Sterilization of surgical instruments is recommended at 104°C (220°F) with wet heat, which means that saturated steam is used for one hour, or sometimes two hours. Sterilization without steam, so-called dry heating, is recommended at typically 171°C (340°F) for two hours. Cooking, then, is a less precise term and does not correlate with the term sterilization. Microwave drying of feces can be done at low enough temperatures to avoid trouble with "cooking odors," which experiment has shown to be strong and disagreeable.

Microwave Heating - Microwaves are radio frequency waves very close in frequency to those used for TV transmissions and aircraft radar. The majority of microwave heating devices utilize a frequency of 2450 megahertz (MHz), which in air results in a wavelength of 12.1 cm. A 350 watt magnetron microwave generator typical of domestic microwave ovens is shown in Figure 43, and weighs less than .45 kg (one pound). The heaviest component of the oven circuit is the transformer at about 5.4 kg (12 lb) seen in the lower center of Figure 44. Except for structural and shielding components total weight of the oven system is about 6.8 kg (15 lb). Microwave fields, whose power is measured in watts (W), have certain properties: they are reflected off metals and do not heat metals, are transparent to certain materials and pass through without causing significant heat as light will pass through glass, and are absorbed by certain materials, resulting in the production of heat. Briefly the primary mechanism of energy absorption pertinent to our application is that of molecular dipole rotation. The dipole referred to is an electric dipole consisting of positive and negative centers of charge separated by a distance. When an external field is brought to bear on an electrical dipole, a dipole moment will be induced in it. A molecule consisting of two atoms will have a dipole moment if the atoms are unequal, and the chemical bond between will establish the distance. Among many others, water, hydrochloric acid, and carbon monoxide molecules have dipole moments responding to the field, and hydrogen, oxygen, and chlorine molecules have not. Some molecules such as paraffin, benzene, carbon tetrachloride, and carbon dioxide contain dipole groups, but symmetrical arrangements cancel the individual group effects. The heat generated involves the total energy dissipative effects of all the elastic distortions, deformations, and displacements which occur under stimulation from the field and from the restoration forces. The heat resulting from this instantaneous and deep penetrating effect is the great advantage of the microwave process.

Due to the potential for danger of exposure to microwave radiation, significant effort has been expended toward microwave containment. The current FDA safety standard for new residential microwave ovens limits the allowable leakage to 1 mW/cm² at any point 5 cm or more from the surface of the oven, a radiation level that is easily met. The current Shuttle limit for microwave radiation is 10 mW/cm² at any point within crewmember range. Typical residential microwave ovens produce 500 to 650 watts of radiated microwave energy and operate at a microwave generation efficiency of 38 to 45 percent.



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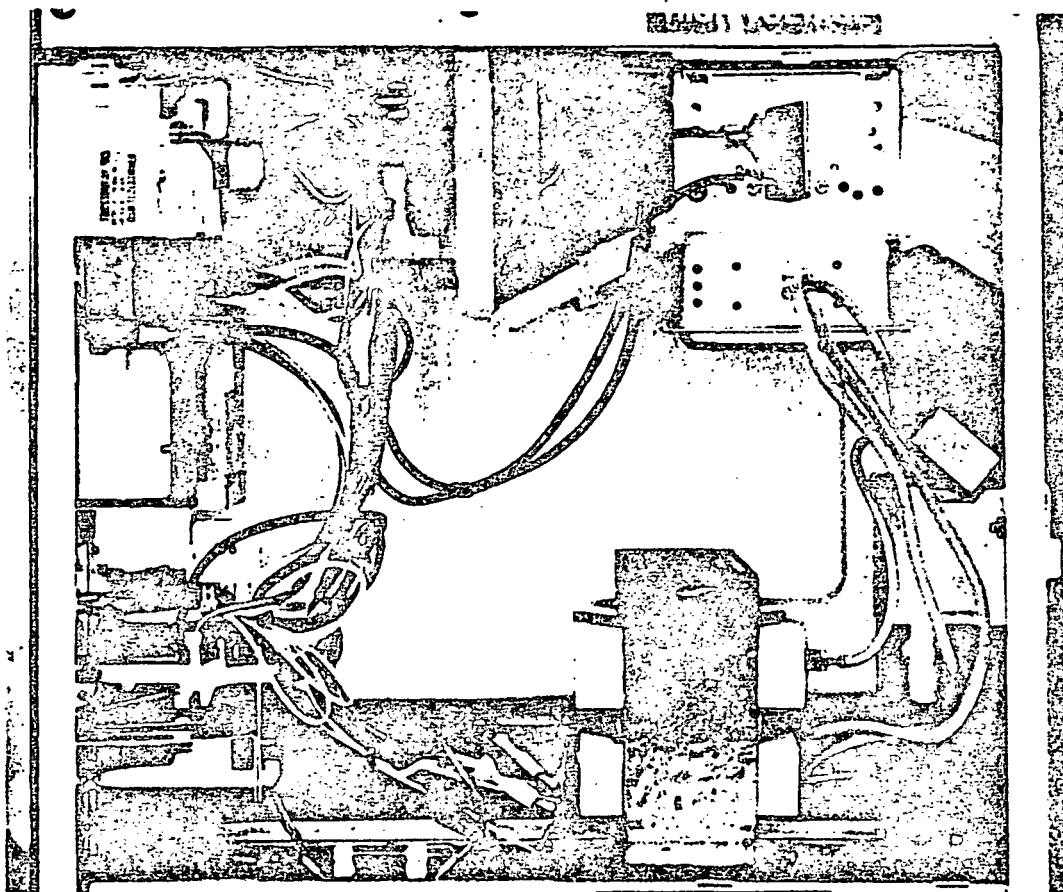
Figure 43
MAGNETRON MICROWAVE GENERATOR



UNITED
TECHNOLOGIES
HAMILTON
STANDARD

SVHSR 8931

GRAPHIC
OF FOUR



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Figure 44
MICROWAVE OVEN COMPONENTS

Desiccation by Microwave Heating - The process of removing water by vaporization requires the addition of heat energy to the material. Microwave heating, through its instantaneous and deep penetration process, offers an ideal means for a homogenous introduction of heat energy in a manner not dependent on the thermal conductivity of the fecal and wipe mixture. Much research has been performed by industry on microwave freeze-drying of foodstuffs and biological material. Basically freeze-drying fixes the volume of the material according to the original dimensions when frozen. The ambient pressure is lowered below the triple point of water, 0.00061 N/m^2 (.0885 psia), and sufficient microwave heat energy is added to sublimate the ice crystals. The resulting product will have a large void network that allows rehydration to a near normal medium. In the case of fecal material the need to rehydrate is not present so the power penalty to freeze and thaw the material, and to reach the triple point pressure is not justified. For our purposes desiccation can be carried out using microwave heat energy at cabin pressure. Cabin air at ambient pressure used as a sweep gas removes the water vapor from the surface of the fecal material that has been heated by microwave energy to a suitable temperature. This temperature, about 93°C (200°F), is to be high enough to provide an adequate water extraction rate but low enough to prevent adverse chemical dissociation and vaporization of undesirable materials. To avoid condensation the sweep gas must be preheated to the process temperature prior to introduction into the desiccant chamber. The energy required for this preheating process can be extracted from the waste heat produced by the microwave generation equipment, as in Figure 42.

Experimental Microwave Desiccation - A test program was conducted to provide evaluation data applicable to ambient pressure desiccation of fecal material using microwave heat energy. Testing was performed using a Sharp Model R-4620 microwave oven with a maximum radiated energy of 650 W. Four other power levels of 455 W, 325 W, 195 W, and 65 W can be set on the oven and are obtained by varying the magnetron duty cycle. The oven output was checked at 650 W and 195 W using a 1,000 g water load and found to be within 5% of the specified power levels.

Initial testing was performed using Oscar Mayer hot dogs, reported by Consumer Reports Magazine to have a fat content of approximately 28% by weight and a water content of approximately 55% by weight (compared to 3% fat and 82% water for nominal fecal material). One of our goals was to desiccate the material without liberating significant fat that would be transferred downstream to coat the duct work or the condensing heat exchanger, so the high fat content of the hot dogs was judged as being desirable.

A sample was encapsulated in a sack made of double thickness #50 hardened filter paper and placed in the oven on a second double thickness of filter paper. The weights of the sample and the filter paper were recorded. A 500 g water load was added and the oven set to the 325 W power level. The oven was run for five consecutive five minute periods with the 500 g water load temperature rise and the total sample weight being recorded after each period. The energy absorbed by the sample was calculated to be 55-60 W, and was determined by subtracting the energy absorbed by the water from 325 W oven output. Enough energy was produced to vaporize approximately 7 g of water each five

minute period. Examinations of the results after a total of 25 minutes in the oven produced the following:

Original sample weight	57.29 g
Final sample weight	19.41 g
Total weight loss	37.88 g
Filter paper weight gain (fat)	6.97 g
Water weight loss	30.91 g

Water removal (% of total weight)	54% (Compared to estimated 55% contained in sample)
Fat removal (% of total weight)	12% (compared to estimated 28% contained in sample)

The desiccated hot dog sample appeared dry, hard, and moderately brittle, and was not significantly reduced in volume from the original volume.

A second series of tests was performed using powdered potato to simulate the fecal solids, and butter to simulate the fat. A sample was prepared to correspond to the previously mentioned proportions of 82% by weight of water, 15% solids (in this case powdered potato) and 3% fat. An additional sample was prepared without fat to determine if the staining on the filter paper was solely done by the fat. The samples were placed in the microwave oven along with a 250 g water load and exposed to ten minute cycles at an oven power output of 325 W. The effective power absorbed by the samples was calculated by the water load temperature rise method to be 125-135 W. The samples were weighed after each 10 minute cycle, and after seven cycles, 70 minutes total exposure, reached a reasonably stable weight level. Following is a summary of the results:

	<u>Sample 1</u>	<u>Sample 2</u>
Initial weight	82 g H ₂ O 15 g Potato 3 g Butter	82 g H ₂ O 15 g Potato no Butter
Final weight	17.65 g	14.39 g

Both samples were dry, hard, and brittle and sample 1, as expected, showed a grease stain on the filter paper where sample 2 had no grease stain. The samples were firmly attached to the filter paper so it was not possible to get a significant weight gain of the filter paper from the butter to determine how much of the butter was retained within the potato matrix. Once again, little volume reduction was noted.

The final testing was performed on a human feces sample. A raw sample weighing 164.89 g was collected in 2.79 g of toilet paper and frozen to facilitate handling. This sample was encapsulated in a double thickness of #50 hardened filter paper and placed in the microwave oven on a second double thickness of filter paper, along with a 250 g water load. The oven power level was set to 350 W and the effective power absorbed by the sample was calculated to be 100-110 W. After four 20 minute cycles the sample weight reached a reasonably

stable level. The final weight of the fecal residue including the fats collected by the filter was 47.29 g which determined the weight loss to be approximately 71%, indicating that the water content of our fecal sample was less than the 82% taken close to the upper end of the 65-85% range in the literature. An examination of the desiccated sample showed it to be hard, dry, and moderately brittle, and to be only slightly reduced in volume from the original state. The filter paper showed a level of grease staining similar to that of the potato and butter sample. Due to the nature of the material, no further examination was undertaken. The odor emitted from the desiccated fecal sample was quite strong and moderately offensive. A similar odor was detected within the oven several hours later; volatile gases driven off the heated sample may have condensed on the cool walls of the oven. After several days of standing with the door open the oven completely lost its odor, perhaps demonstrating the non-persistent nature of the odor producing material. Charcoal beds are customarily employed to remove odors of this nature and bed sizing will be discussed in conjunction with the system sizing sections of this study.

A further experiment using human feces was conducted at a reduced temperature, operating the oven at 150 W power rather than 350 W. In this instance the residue was again hard and somewhat brittle, and was much reduced in thickness. Odor was very faint in comparison to the previous experiment and residual odor in the oven was almost undetectable. Breathing air containing the odor while wearing a charcoal filter type painter's respirator resulted in no odor being detectable.

A parallel may be drawn between the odor of the desiccated potatoes and that of the desiccated feces. The potato odor was the faint but familiar odor of cooked potatoes, while that of the odorous desiccated feces must be called characteristic of the chemical changes wrought by cooking. In the second case the faint and slightly strange odor of desiccated feces resulted evidently because little if any chemical change took place at the lower temperature, and desiccation was accomplished without cooking.

5.2.2 Thermoelectric Refrigeration

Refrigeration of wastes can be provided easily in the bag, canister or sleeve commodes by circulating cold air through them, and by thermally insulating their exterior surfaces. In Figure 45 a fan circulates cold air through insulated ducts into the commode at the transport tube, and out again on the other side of the hydrophobic filter barrier that supports the wastes, for return to the thermoelectric heat pump. Refrigeration at a nominal 1°C (34°F) will reduce the metabolic activity of bacteria in feces to a low level. This temperature is substantially less than the conventional temperature of 4°C (40°F) used for the domestic refrigeration of foods, which is quite practical in limiting bacterial activity. It must be above the freezing point to avoid an accumulation of frost on the heat transfer surfaces that could obstruct the circulating air flow and necessitate a defrosting and moisture removal cycle. A temperature control set for 1-2°C (33-35°F) avoids frost and makes use of a substantial temperature reduction from the 7°C (45°F) chilled water heat sink available in the Space Station. Relatively low power is sufficient to operate

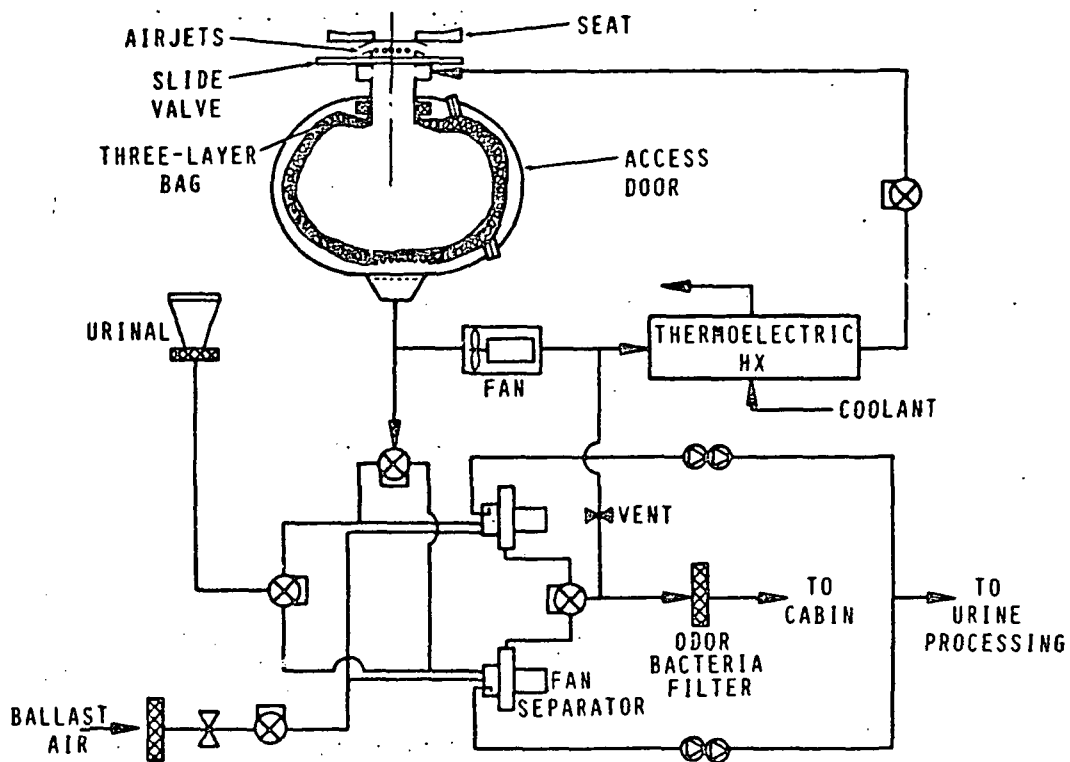


Figure 45
THERMOELECTRIC REFRIGERATION

the cycle, at 130 watts. Although this electrical load is continuous, because the heat leakage through the commode insulation is continuous, the Space Station weight penalty is based on maximum power, and there is not a further penalty for duration. A reduction in temperature to -18°C (0°F) would increase the electrical power load by an order of magnitude and thereby make thermoelectric refrigeration unfeasible for this purpose. Circulating cold air from a thermoelectric heat pump enables the waste contents of the commode to be refrigerated quite simply, with little additional volume, weight and power. The fan separator runs while the commode is in use and refrigeration is applied only between uses. Consequently fan separator power of 100 watts does not increase the penalty. Once the commode is filled to its capacity the wastes must be removed. If they are to be stored, the storage compartment must also be insulated and refrigerated, further increasing system weight, volume and power. Elimination of wastes by jettison and destructive reentry would, if employed, eliminate this necessity and for long durations produce a saving.

Thermoelectric refrigeration is attractive in its absence of moving parts, except for the circulating fan. Its reliability will consequently be high. Noise is only from a fan in a fully enclosed circuit and is comparatively quiet. It makes use of air as the heat transport medium which is desirable because of simplicity, low weight, and lack of hazard or difficulty with respect to leakage. Thermoelectric chips are square with an area of 39 mm (1.56 in) and a thickness of about 3 mm (0.12 in). A quantity of 14 chips has been estimated as sufficient to cold a $.071 \text{ m}^3$ (2.5 ft^3) commode to 1°C (34°F) using 51 mm (2 in) thickness of insulation. These chips will have a total area of $.014 \text{ m}^2$ (22 in^2), but will be attached to fins in narrow passages as in a compact heat exchanger.

As illustrated in Figure 46 the wastes in the commode will be held at the air inlet temperature which, at 1°C (34°F), is 3°C (5°F) cooler than the air outlet temperature. This benefit results from the radially outward airflow past the wastes and through the hydrophobic filter barrier that supports them in bag, cup or sleeve commodes. Heat flow is radially inward through the insulation that surrounds the commode. This heat is absorbed by the air that has already passed through the filter barrier and has turned parallel to the commode wall. It is exhausted to the fan and heat pump. There is sufficient pressure loss in the filter barrier, $.12 \text{ N/m}^2$ (5 in H_2O), that the space on both sides of it is conveying air at very low velocity. Thus there is an effective plenum chamber on each side and flow is distributed in a way that tends to be uniform over the surface. Air collecting in the outer plenum absorbs the heat flux coming through the insulation and rises in temperature to a maximum at the outlet.

In Figure 47 a circulating flow of $1.1 \text{ m}^3/\text{min}$ (39 scfm) is seen to traverse the loop of fan, thermoelectric heat pump, commode, and back to the fan. Air leaving the heat pump at 1°C (34°F) nominally, enters the commode and rises to 4°C (39°F) goes to the fan where mechanical work done on the air, raising the temperature to 6°C (42°F), and then passes to the heat pump. Pressure losses on the loop are made up by the fan, amounting to about $.25 \text{ N/m}^2$ (10 in H_2O) with half the loss taking place through the hydrophobic filter waste barrier.

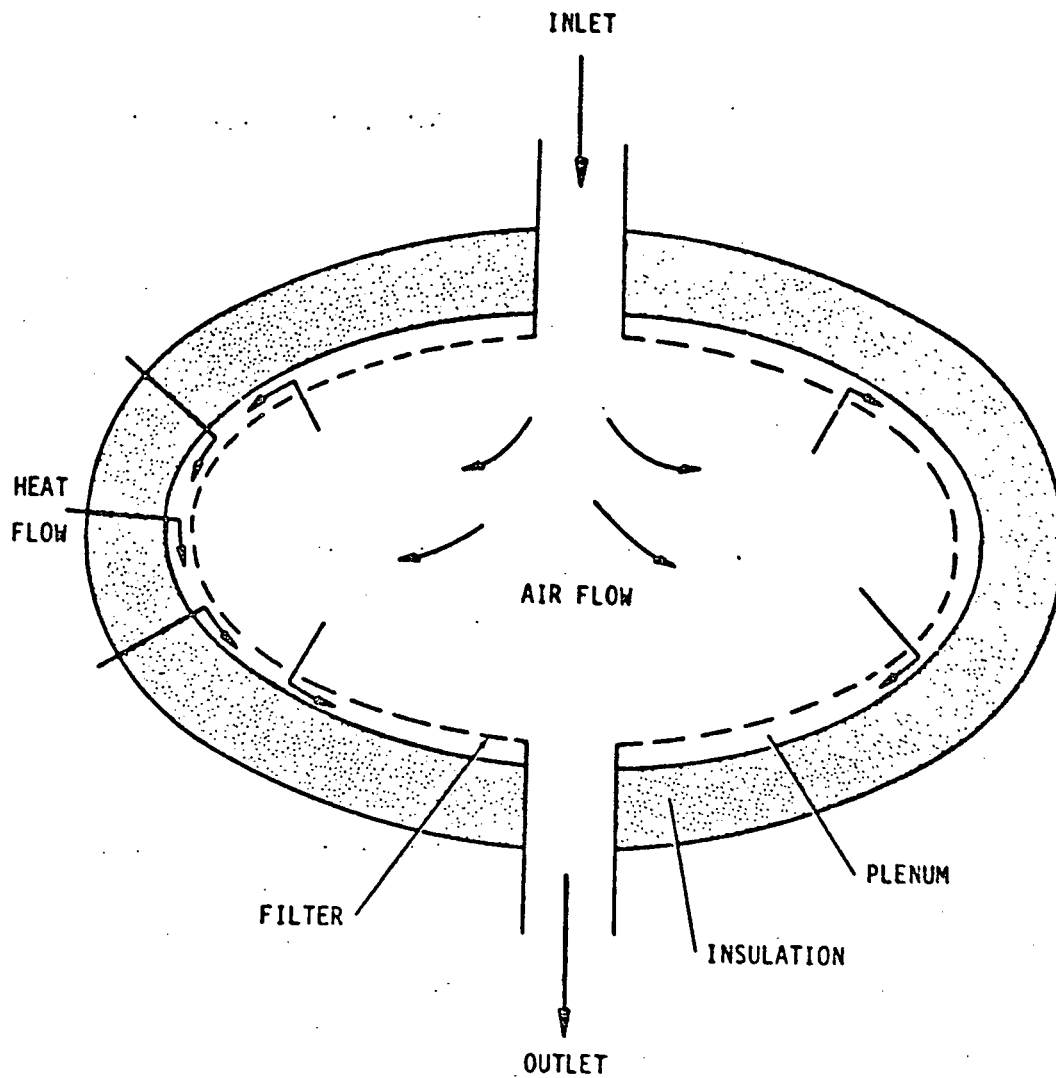


Figure 46
REFRIGERATED COMMODE

211000 JOULES/HR (200 BTU/HR) HEAT LEAK THRU 51 MM (2 IN) FOAM
21100 JOULES/HR (20 BTU/HR) HEAT LEAK THRU DUCTS

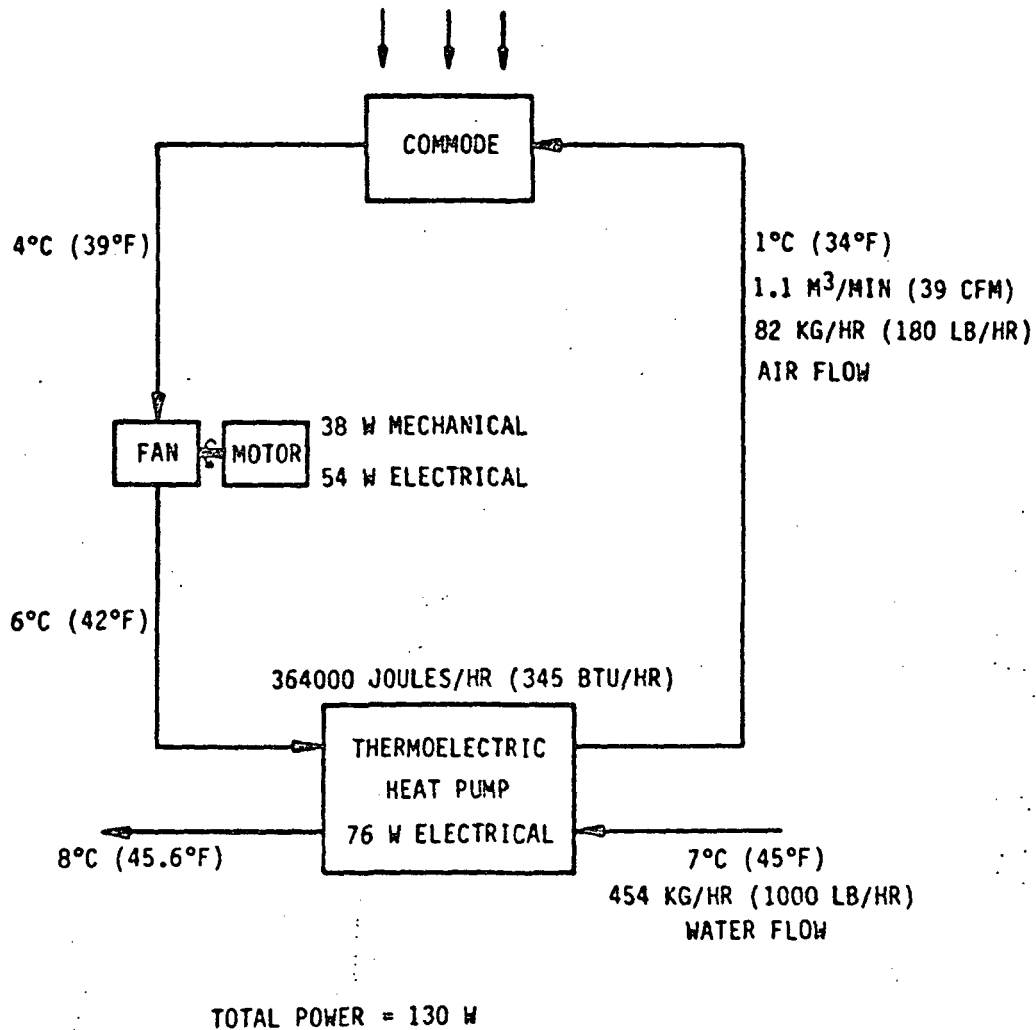


Figure 47
THERMOELECTRIC COOLING LOOP



While thermoelectric refrigeration is feasible at a storage temperature of 1°C (34°F) and is not feasible at -18°C (0°F), other methods of refrigeration could be used. A freon vapor cycle has been considered for -18°C (0°F). It would consume twice the power that the thermoelectric heat pump requires at 1°C (34°F). It would accumulate frost on the evaporator and a defrost at suitably high velocity of circulating air and a fan separator would be required. Freon containing equipment must be isolated from the normally occupied parts of the Space Station, and heat must be transferred through a structurally acceptable partition. This requirement seriously impairs the ability of the vapor cycle obtain a low temperature without excessive power consumption. Considering these factors the advantage of reducing temperature much below 1°C (34°F) are comparatively slight while the costs in weight, volume and complexity are large. A tradeoff in Appendix C shows the resultant ratings. Another approach to lower storage temperature is that of air cycle refrigeration which avoids the need to isolate the working fluid, cabin air. It can readily obtain -18°C (0°F) temperatures but both power consumption and noise are quite high, power being over 4 times that of the 1°C (34°F) thermoelectric heat pump. Here again a defrost cycle must be provided together with velocities to clear the heat transfer surfaces of melted frost, and a fan separator to eliminate the water. In Appendix C this cycle is seen to trade-off less favorably than the vapor cycle.

In summary, if treatment by refrigeration is considered, a temperature slightly above freezing is advantageous, and can be provided very simply at low power with a thermoelectric heat pump and an air circulating fan.

5.2.3 Biodegradation

Fecal wastes contained within a commode, whether of bag, sleeve or canister configuration, Figure 48, will undergo a natural process of bacterial metabolism. Bacteria which may comprise 40% of the mass of feces tend to consume the organic nutrients present, and in doing so they generate their own byproducts. In the absence of copious amounts of water to dilute them these byproducts act to inhibit the further metabolism of the fecal wastes. Experimental results summarized in Figure 49 show the generation of carbon dioxide and methane gases by many samples of human feces from various individuals and diets, stored at the warm temperature of 30°C (86°F). It can be seen that CO_2 is evolved over 8 or 10 days and then stops. Its total volume at standard pressure reaches a maximum of about 8 times the original volume of feces and at least 4 times the original volume. In a like manner CH_4 is generated, but for only about 3 days. Its volume may reach only 0.7 times that of the feces. Other gases, notably hydrogen, were generated at substantially lower levels, hydrogen sulfide being a trace. Limited gas generated of limited or negligible toxicity for a few days appears to be the whole result of storing unwetted feces at room temperature. There is no escape of unwanted substances or bacteria when adequate containment is provided, the CO_2 being only 0.2% of the amount resulting from respiration and representing a negligible load increment to the CO_2 removal system. Methane, which is nontoxic, is generated in about the same amount as is produced in flatus, and is of such a small quantity that it would take some 45 years to reach the lower limit of flammability in a 6 man cabin of 170 m^3 ($6,000 \text{ ft}^3$) volume. Figure 50 summarizes these quantities.

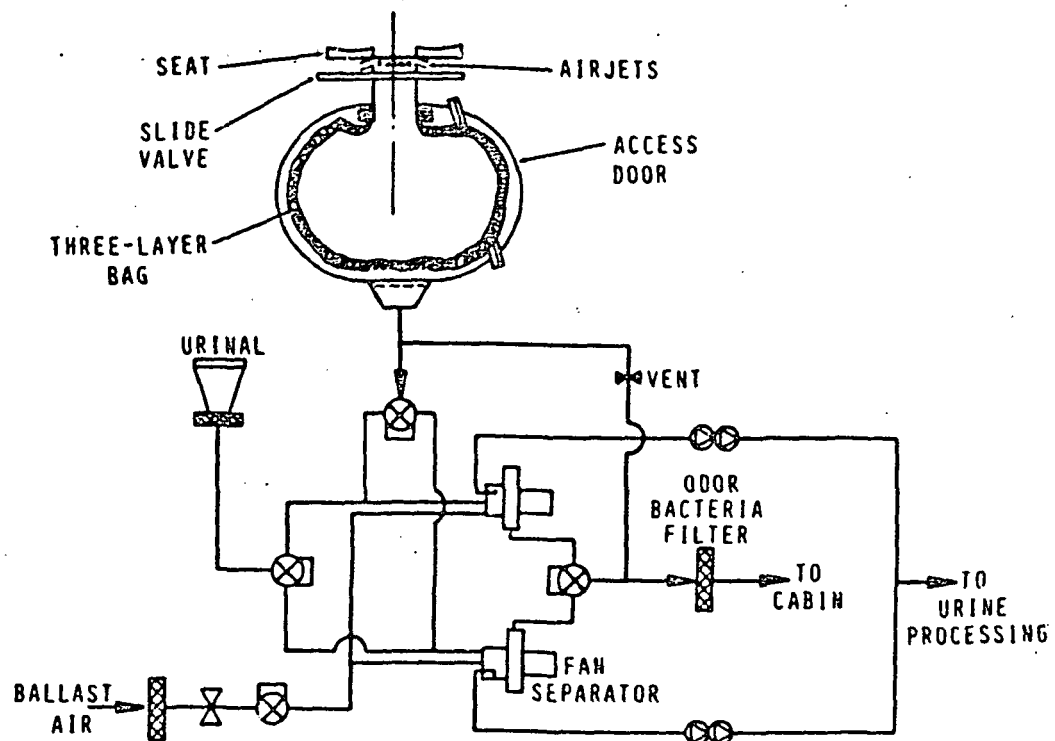
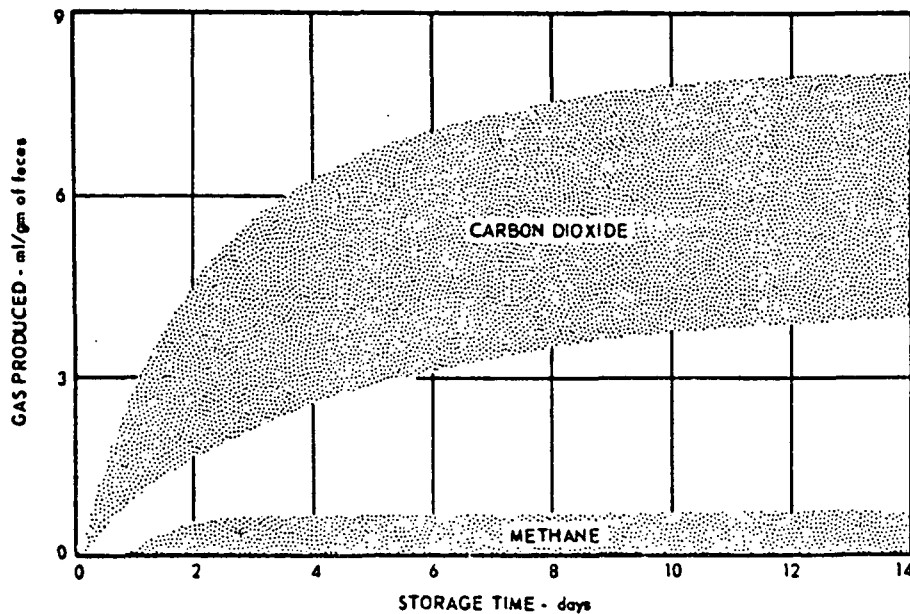


Figure 48
BIODEGRADATION



The shaded areas define the ranges of values for the two major gases produced when feces are stored at 86°F (30°C) for a period of two weeks. Some specimens produced traces of hydrogen and hydrogen sulfide as well.

Source: Wheaton et al. [62].

Bioastronautics Data Book (1964)

Figure 49
GASES PRODUCED FROM UNTREATED FECES

STORAGE TEMPERATURE	30°C (86°F)
TIME TO COMPLETE (95%)	
CO ₂	8 DAYS
CH ₄	3 DAYS
FECES CO ₂ WEIGHT/RESPIRATORY CO ₂ WEIGHT	0.183 PERCENT
TOTAL WEIGHT OF CO ₂ PRODUCED	0.002 KG/MD (0.004 LB/MAN-DAY)
TOTAL WEIGHT OF CH ₄ PRODUCED	0.00006 KG/MD (0.00013 LB/MAN-DAY)
TIME TO FILL 170 M ³ (6000 FT ³) - 6 MAN CABIN TO LOWER LIMIT OF INFLAMMABILITY IN AIR	45 YEARS

Figure 50
CO₂ AND CH₄ PRODUCED FROM FECES

From the foregoing evidence a feasible scheme of nonventing fecal waste treatment for Space Station is to let the bacteria provide their own treatment. In the author's experience an intermittently used outdoor commode with complete drainage, that is, an outhouse without a pit resting on a slope, has been observed to preserve a mound of feces without discernible change in volume over a period of years. This rudimentary observation tends to reinforce the implications of the data of Figure 49. Self-treatment by the bacteria is called biodegradation in the sense that some metabolism takes place, and there is a change in the chemical constituents of the wastes. Finally the generation of inhibiting byproducts, usually resulting in increased acidity of the feces, marks the end of this biodegradation process by limiting the evolution of gas.

Biodegradation as a waste treatment process requires the least of equipment weight, volume, power and complexity of any process. No more is required than to contain the waste feces and paper, including their bacteria and odors, while permitting evolved gases to escape to the cabin air. Carbon dioxide will be removed by the cabin CO₂ removal system, and the small quantity of methane will ultimately be lost by unavoidable overboard leakage, air lock ullage and the like. No control is needed for temperature, humidity or pressure.

Sanitation requirements for biodegradation do not differ from those for other kinds of waste treatment. Containment and isolation from living space is necessary for each, because such processes as drying and refrigeration produce only temporary inactivation of the bacteria and do not reduce the need for sanitary practices. Sterilization introduces new hazards such as toxic biocides, products of combustion or radiation, depending on the mode, that must also be isolated from the cabin. Anything less than perfect sterilization with perfect reliability retains the original need for sanitation applicable to biodegradation.

Since gas is generated by biodegradation, sufficient venting in storage must be provided that pressure does not build up in the containment vessel. This amount of venting is very small and an ordinary leak should take care of it. Odors are also present as gases in trace quantities. They make it important that the gases leaking from storage are vented by way of an activated charcoal bed for the organic odors with permanganate and activated alumina for the inorganic odors such as hydrogen sulfide and sulfur dioxide. Such an odor filter is required during use of the commode and consequently is available for the storage vent line.

5.2.4 Treatment Tradeoff Comparison

Characteristics of waste treatment methods, in terms of weight, volume and electrical power required are tabulated in Figure 51. Using these data and the foregoing discussions a tradeoff comparison has been made on Figure 52 of the microwave drying, thermoelectric refrigeration and biodegradation concepts of waste treatment.

	<u>WEIGHT*</u>	<u>VOLUME*</u>	<u>POWER (W)</u>
MICROWAVE DRYING	64.9 KG (143 LB)	.387 M ³ (13.7 FT ³)	305
THERMOELECTRIC REFRIGERATION	48.6 KG (107 LB)	.357 M ³ (12.6 FT ³)	166
BIODEGRADATION	42.4 KG (93 LB)	.334 M ³ (11.8 FT ³)	100

*BASED ON FRONT DOOR COMMODE

Figure 51
CHARACTERISTICS OF WASTE TREATMENT METHODS

(STATIONARY DISK CANISTER)

CODE

- 5 EXCELLENT
- 4 VERY GOOD
- 3 GOOD
- 2 FAIR
- 1 POOR

	<u>CONCEPT</u>	<u>MICROWAVE DRYING</u>	<u>THERMOELECTRIC REFRIGERATION</u>	<u>BIODEGRADATION</u>
<u>ABSOLUTE</u>	PERFORMANCE	S	S	S
S = SATISFACTORY	SAFETY	S	S	S
U = UNSATISFACTORY	AVAILABILITY	S	S	S
<u>PRIMARY</u>	CREW ACCEPTABILITY	4	4	3
	PAPER DISPOSAL	5	5	5
	NOISE	4	4	4
	CONTAMINATION	4	4	4
	RELIABILITY	5	5	5
	SCORE	22	22	21
<u>SECONDARY</u>	RETROFITABILITY	4	4	5
	GROWTH POTENTIAL	5	5	5
	POWER	4	3	5
	VOLUME STORAGE	5	5	5
	WEIGHT	4	4	5
	COST TO DEVELOP	4	4	5
	SERVICING MAINTENANCE	4	4	5
	EASE OF OPERATION	5	5	5
	SCORE	35	34	40

Figure 52
TRADEOFF - WASTE TREATMENT

Microwave drying, thermoelectric refrigeration, and biodegradation meet the absolute criteria of performance, safety, and reliability at a satisfactory level. No special precautions are necessary other than to provide the electromagnetic radiation shielding and interlocks that are common to the domestic microwave oven. Performance is reached by each to match that of overboard venting in the Shuttle which inhibits the metabolic activity of bacteria in feces by drying. Microwave drying does the same. Thermoelectric refrigeration inhibits by means of low temperature storage and biodegradation inhibits naturally by the self-generated chemical concentrations of metabolic byproducts.

Primary criteria for the three are closely equivalent. Biodegradation suffers the loss of a point in scoring on the assumption that the crew might prefer some overtly active treatment in preference to the time required for natural inhibition to take place.

Secondary criteria show differences. Retrofitability assumes the Shuttle commode to be applied to the Space Station, and equipment volume is greater for microwave and thermoelectric than for biodegradation. Growth potential is excellent for each since mission duration can be extended indefinitely by removing wastes from the commode in flight. Power scores high for biodegradation because, except for the fan separator used for each concept to entrain wastes, it requires none. Microwave power receives an intermediate score for its presumed availability at off peak times in the daily cycle. Thermoelectric power receives a lower score because, although power is at a low level, it is continuous.

Volume comparison is based on storage volume because mission duration is long, and each is equivalent because it thereby depends on the commode concept rather than the treatment. Jettison and destructive reentry could greatly affect actual storage volume, but it would be independent of a treatment concept. Weight comparison is based on equipment weight and biodegradation has no weight associated with treatment, while the other two involve some 6.8 to 9.1 kg (fifteen to twenty pounds) weight increment without reference to the power weight penalty. Cost comparison is based on cost to develop the treatment process rather than that of expendables used in providing turnaround of the commode. Both microwave and thermoelectric concepts are more complex than biodegradation, and, while each needs testing to obtain design data, biodegradation must score higher. Servicing comparison is based on the difficulty of maintenance of equipment rather than of emptying the commode. Here again microwave and thermoelectric concepts are equivalent while biodegradation is superior. Finally, ease of operation is uniform for each because that is dependent on the commode concept rather than that of treatment.

As a consequence of these trade-off comparisons, it is to be observed that biodegradation should be eliminated because it does not quite tie the primary criteria score. However, it is very close and a revised crew acceptability rating could make it equivalent. On the basis of secondary criteria, it then would become an obvious choice. Without it, the microwave drying concept edges out the thermoelectric refrigeration concept by one point of score. These trade-offs are too close to make a selection until more is known, and an important part of such knowledge is the design test data required for each of the three concepts.

A further study of trash disposal for other than feces and toilet paper on the Space Station is needed for an ultimate choice of treatment. If fecal wastes are to be disposed of together with other trash, the whole problem must be considered as a unit. Such factors as destructive reentry versus return, and containers for fecal wastes versus compartmental storage must be addressed.

5.2.5 Testing Needed to Evaluate Treatment Methods

Biodegradation - Store fecal wastes with paper at room temperatures, atmospheric pressure, measuring types and volumes of gases produced from a variety of individuals and diets. Effects of relative humidity and the addition of small amounts of water should be observed. Nature and quantity of odors should be observed, using chromatographic evidence, and the capacity of activated charcoal and other absorbents such as purafil for removing these odors should be measured.

Refrigeration - Store fecal wastes with paper at various refrigeration temperatures, including 7, 4, 1, -1 and -18°C (45, 40, 34, 30 and 0°F), at atmospheric pressure, measuring types and volumes of gases produced from a variety of individuals and diets, preferably by subdividing samples from the biodegradation test above. Effects of relative humidity and the addition of small amounts of water should be observed. Nature and quantity of odors should be observed, using chromatographic evidence, and the capacity of activated charcoal and other absorbents such as purafil for removing these odors should be measured.

Microwave Drying - Dry fecal wastes and paper at various rates of heat input per unit of mass, measuring drying times at the point where weight reduction ceases. Measure the temperature levels attained. Measure the types and volumes of gases produced. Obtain sample from a variety of individuals and diets, preferably by subdividing samples from the refrigeration and biodegradation tests above. Effects of the addition of small amounts of water should be observed. Nature and quantity of odors should be observed, using chromatographic evidence, and the capacity of activated charcoal and other desorbents such as purafil for removing these odors should be observed, and correlated with the maximum temperature measured in the sample during drying.

5.2.6 Destructive Reentry

As an alternative to storage for long durations, destructive reentry is disposal of solid wastes by jettison from the Space Station. Velocity of the jettisoned wastes is different from the orbital velocity of the Space Station by some minute amount, which is sufficient to remove it to great distances from the Space Station in a short time. Ultimately, in a few years, its orbit decays to the point that atmospheric heating destroys it, burning to gaseous products and ash. There is no sensitivity to jettison velocity or direction in that relative velocity is so low that orbital changes do not noticeably affect the time of destructive reentry. Again, there is little hazard of impact by a resupply vehicle approaching or leaving the Space Station because of the wide separation distances and the low relative velocities.

Since low relative velocities are adequate, only a small amount of energy is necessary to accelerate the jettisoned wastes. On the basis of jettison in 52.5 man-day units, about 6.8 kg (15 lb) of wastes in a 1 kg (2 lb) container can be accelerated to 3 m/s (10 fps) by 35.8 joules (26.4 ft lb) of energy. As in Figure 53, this energy would be supplied by a piston having cabin air pressure initially on one side and vacuum on the other. For a 152 mm (six in) diameter piston, stroke would be only 23 mm (0.9 in). It could be returned to the starting position by hand with a third of the energy a 68 kg (150 lb) man expends in doing one push up. A pneumatic spring, in effect, would thereby expend no mass overboard if the piston were sealed by a diaphragm. Cabin air would be expended in the ullage volume of the waste container chamber if it were not pumped out by the airlock pump. Figure 54 shows jettison system volume and weight versus velocity of ejection. The lowest velocity systems are seen to be attractively light and small.

At a rate of one jettison per week the volume of cabin air lost would be negligible and the distribution of debris in space would be extremely diffuse, and of a definitely limited duration in low earth orbit.

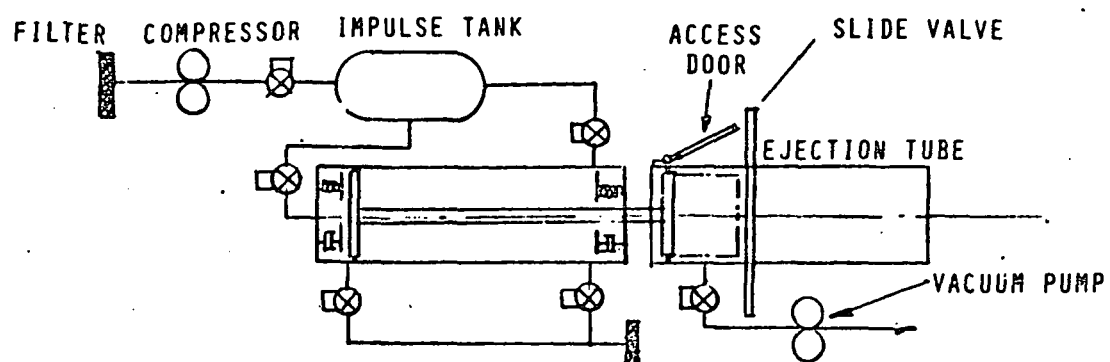


Figure 53
JETTISON

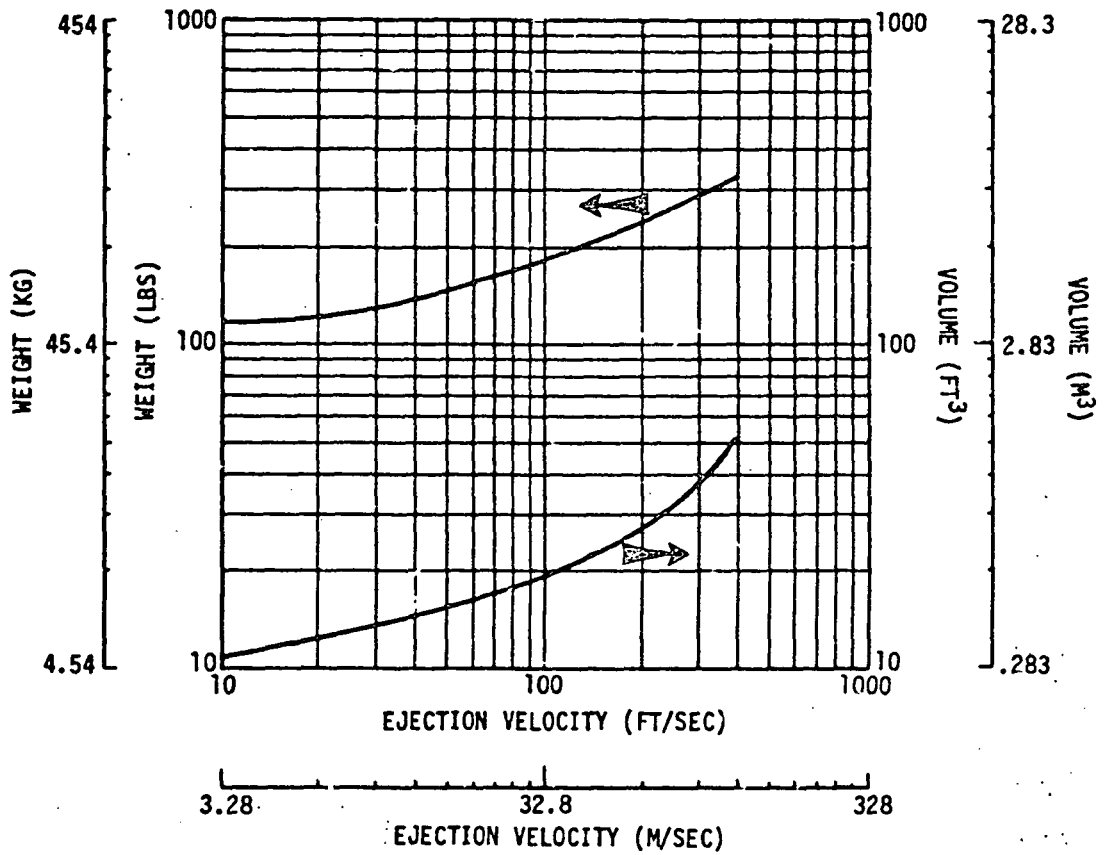


Figure 54
JETTISON SYSTEM VOLUME/WEIGHT VS EJECTION VELOCITY



6.0 SYSTEM REQUIREMENTS DEFINITION DOCUMENT

Introduction

In this document requirements are defined for a representative flight test article for the Stationary Disk Canister Commode concept.

Objectives

Ground and flight tests will be conducted to determine the functioning, waste compaction and rapid changeout of the Stationary Disk Canister Commode concept.

Test Requirements

Observe the effective entrainment of feces and toilet paper and wet wipers through the long transport tube and into the representative test canister. Observe the scooping action of the compaction disk at the lower skirt edge and the wiping action at the upper lip. Vary the snugness of fit over a small range by setting the disk up on a mandrel and grinding off the outside diameter. Observe the wedging action of a subsequent disk skirt around the outside of a previously inserted disk and the effect of draft angle upon it. Note the effect of a chamfer at the top of the disk to enhance the starting of the wedging motion. Observe the force necessary to obtain full compaction, and measure compaction versus applied force. Observe hand hold points effective in weightlessness to react the compaction force. Observe any indication of leakage from beneath the protective film. Observe the quantity and character of any wastes that may not be scooped off the mesh. Determine whether they coat the mesh obstructing airflow or whether they pass through to load the filter surface. Observe the motion of feces as affected by the airflow pattern and whether they are brought forcibly against the mesh or not. Determine airflow velocities and pressure losses at critical points within the circuit in search of possible inefficiencies. Conduct ground tests and correct deficiencies before attempting a flight test.

Hardware Requirements

Fabricate a test canister from metal, preferably stainless steel so that it may be cleaned for reuse many times. Ensure an accurate and rigid inner mesh liner so that errors in fabrication do not vitiate the results of testing the wiping action of compaction disks. Fabricate several compaction disks of a fairly stiff elastomeric material, preferably by injection molding. These should be full size, and have a 102 mm (4 in) diameter. Fabricate a mockup commode adhering carefully to Shuttle commode dimensions for the following key elements: crew member restraints, seat, air jets, slide valve, transport tube diameter. Make the transport tube a smooth, accurate cylinder having a Teflon surface. For the canister wire mesh size select 16 mesh with about .3 mm (.012 in) wire diameter. Weld the mesh into a cylindrical shape and to its end fittings. Use a potting compound for sealing the upper end that is compatible with a steam cleaning process for reuse.

Refer also to the cup commode flight experiment in this report and to Figure 20 to show a similar procedure intended for evaluating cup compaction in the canister as contrasted with disk compaction.



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Reference Documents

Reference is made to Shuttle Document No. MC282-0069 from Rockwell International and incorporated as Appendix C of Contract NAS 9-17183. This document, titled Collector Subsystem, Waste, defines the Space Shuttle commode and thereby the quantitative factors to be simulated by test. Hamilton Standard Drawing No. SVHS 109313 defines to scale the Stationary Canister Commode concept to be embodied in the test mockup. Materials to be used are optional as are mountings and connections. Airflow of $0.85 \text{ m}^3/\text{min}$ (30 scfm) must be provided at suction conditions equivalent to those specified in document (Rockwell International) MC282-0069.

Testing

Ground tests will be performed by actual use of the commode by test subjects, and the functioning, compaction and rapid changeout will be conducted in simulation of a Shuttle mission. There is no need to provide vacuum drying of the feces to accomplish the objectives of this test. Flight tests will be performed to verify collection, compaction and the ease and rapidity of changeout in weightlessness.

Results

When the test series is completed sufficient knowledge and experience will be available to evaluate the concept, and to carry out the design of flight prototype hardware.



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APPENDIX A

TRADEOFF CRITERIA

APPENDIX A

Tradeoff Criteria

A design study necessarily involves a comparison of concepts in which values are attached to significant criteria. A tradeoff can be made among them allowing a significant advantage to make up for, perhaps in part, a significant disadvantage. Some criteria are too important to be traded away in favor of some lesser criterion however attractive. In this vein three levels of criteria (Fig. A1) have been taken, namely absolute, primary and secondary criteria.

Absolute Criteria - These (Fig. A2) must be met at a satisfactory level to permit the concept to be considered further. They consist of performance, safety and availability. Performance, defined as the capability of performing all necessary functions, includes the seventeen requirements of the work statement (Fig. 2) in addition to feces separation, collection and containment given as criteria. When four criteria, feces separation, collection and containment, together with body stabilization are combined into a single criterion called performance, no loss in degree of discrimination results. The reason is that each is taken as an absolute criterion, a complete necessity, before the concept may be judged suitable for further study. This criterion may be summarized by the statement that the concept must be capable of all necessary functions. Safety is the capability of being made free of hazards. Availability is taken as the capability of being developed for practical use by 1987, and thereby involves a judgement upon design risk.

Primary Criteria - Primary criteria (Fig. A3) are of first importance to a concept that meets the absolute criteria and becomes eligible for consideration. These are considered important enough to permit the elimination of any concept that does not reach first place in scoring upon them. At the same time they are basic and general enough so that several relatively good concepts may attain a tied score and become eligible for further consideration. They consist of crew acceptability, paper disposal, noise, contamination and reliability. Crew acceptability is the relative willingness of crew members to use a waste collection system based on a particular concept. Paper disposal is the ability of the subsystem to accept both feces and paper without significant impairment of function. Noise is noise level relative to that of the existing Shuttle subsystem without slinger. Contamination is the relative unlikelihood of contaminating the surroundings by whatever means. Reliability is a measure of relative simplicity and maintainability of equipment, as distinct from servicing by removal of wastes and restoring supplies.

Secondary Criteria - Secondary criteria (Fig. A4) are important to the actual tradeoff of advantages and disadvantages of concepts not eliminated by inadequacies. It is the selection of an optimum choice among acceptable concepts. These criteria are retrofitability, growth potential, power, volume, weight, cost and servicing. Retrofitability is the relative ease of interfacing with the Space Shuttle waste collection subsystem, attributing credit to the minimum amount of change required to incorporate the concept. Growth potential is the relative feasibility of using the concept for extended mission



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ABSOLUTE - MUST BE MET AT SATISFACTORY LEVEL

PRIMARY - RATE 1-5 AND ELIMINATE ALL BUT BEST

SECONDARY - RATE 1-5 AND SELECT BEST

**FIGURE A-1
TRADEOFF CRITERIA**



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PERFORMANCE - MUST BE CAPABLE OF ALL NECESSARY FUNCTIONS

SAFETY - MUST BE MADE FREE OF HAZARDS

AVAILABILITY - MUST BE CAPABLE OF DEVELOPED USE BY 1987

FIGURE A-2
ABSOLUTE TRADEOFF CRITERIA



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CREW ACCEPTABILITY - RELATIVE WILLINGNESS TO USE

PAPER DISPOSAL - ABILITY TO CONTAIN BOTH FECES AND PAPER

NOISE - RELATIVE NOISE LEVEL

CONTAMINATION - UNLIKELIHOOD OF CONTAMINATING SURROUNDINGS

RELIABILITY - RELATIVE SIMPLICITY AND MAINTAINABILITY

FIGURE A-3
PRIMARY TRADEOFF CRITERIA

RETROFITABILITY - EASE OF SHUTTLE INTERFACE

GROWTH POTENTIAL - FEASIBILITY FOR LONGER MISSIONS

POWER - RELATIVE POWER CONSUMPTION

VOLUME - RELATIVE PACKAGE VOLUME

WEIGHT - RELATIVE FIXED WEIGHT WITH SUPPLIES

COST - RELATIVE DEVELOPMENT COST

SERVICING - EASE OF EMPTYING AND RECHARGING

EASE OF OPERATION - USER CONVENIENCE

FIGURE A-4
SECONDARY TRADEOFF CRITERIA

duration to and exceeding 210 man-days capacity. Power is relative power consumption, pertinent to installed wire size in the Shuttle and also to the equivalent weight penalty in the Space Station. Volume is relative package volume, resolving into stored waste volume and volume of supplies outside the Shuttle space envelope for 210 man-days capacity. Weight is relative fixed weight with supplies. Cost is relative cost to use in the Shuttle, and development cost of treatment in Space Station. Finally, servicing is defined as the relative ease of removing wastes from the subsystem for turnaround between flights, or periodically during flight, and the restoring of expendable supplies used in waste collection for the Shuttle. For Space Station it is ease of maintenance.

Work Statement Criteria - Design and tradeoff criteria identified in the work statement are tabulated on Fig. A5 to show their equivalence with those of the study. Of these the following are not changed from the existing Shuttle waste collection subsystem, for which, according to the astronauts' comments, satisfactory levels of attainment have been reached:

Feces Separation - Air entrainment at 30 scfm airflow as the existing Shuttle commode is retained as a demonstrated method.

Feces Collection - Collection by air passing through a permeable surface, thereby conveying the entrained feces and paper to that surface and stopping them, is retained as a demonstrated method. No slinger is incorporated as in the existing Shuttle configuration, for which satisfactory flight use is reported, and this feature is retained as a demonstrated method.

Feces Containment - Containment of feces and moisture associated with them by means of hydrophobic permeable membranes has been retained as a demonstrated method. Elimination of the slinger has already prevented the forcible ejection of feces chunks and powder from the commode, and the inward fan flow prevents outward leakage.

Body Stabilization - The flight tested and approved body stabilization method has been retained in all its physical details, with the exception for some concepts of the horizontal distance from the foot holds to the seat, and the exception of minor shape changes to the hand holds.

Noise - Concepts evaluated for the Space Shuttle do not contain any rotating machinery or other noise generating components other than the fan separator already a part of the system.

Retrofitability - Each concept evaluated has been required to be entirely retrofitable within the space envelope of the existing Space Shuttle waste collection subsystem, making use of all existing interface connections. Furthermore most of the existing components such as fan separators, valves, filters, ducts and controls retain the same configuration and position as in the existing subsystem.

Power - Concepts evaluated for the Space Shuttle do not require any power other than for the fan separator already a part of the system.



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STUDY CRITERIA

WORK STATEMENT CRITERIA

ABSOLUTE

PERFORMANCE

FECES SEPARATION
FECES COLLECTION
FECES CONTAINMENT
BODY STABILIZATION

SAFETY
AVAILABILITY

DESIGN RISK

PRIMARY

CREW ACCEPTABILITY
PAPER DISPOSAL
NOISE
CONTAMINATION
RELIABILITY

PAPER DISPOSAL
NOISE

SECONDARY

RETROFITABILITY
GROWTH POTENTIAL
POWER
VOLUME
WEIGHT
COST
SERVICING
EASE OF OPERATION

RETROFITABILITY
POWER
WEIGHT
COST
MAINTAINABILITY
EASE OF OPERATION

FIGURE A-5
EQUIVALENCE OF CRITERIA



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APPENDIX B

UNCOMPETITIVE COMPACTION CONCEPTS



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APPENDIX B

In this appendix five concepts are illustrated that were considered as compaction means and were rejected. They are listed in Figure B1 and depicted in Figures B2-B6. None of these reached the level of feasibility of the concepts described in the main body of the report.

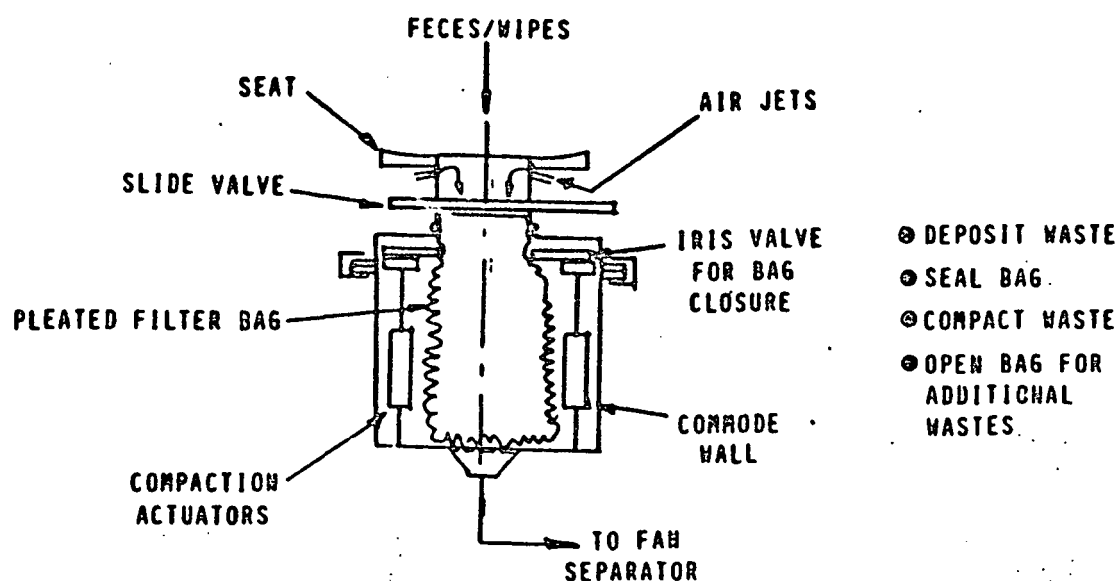


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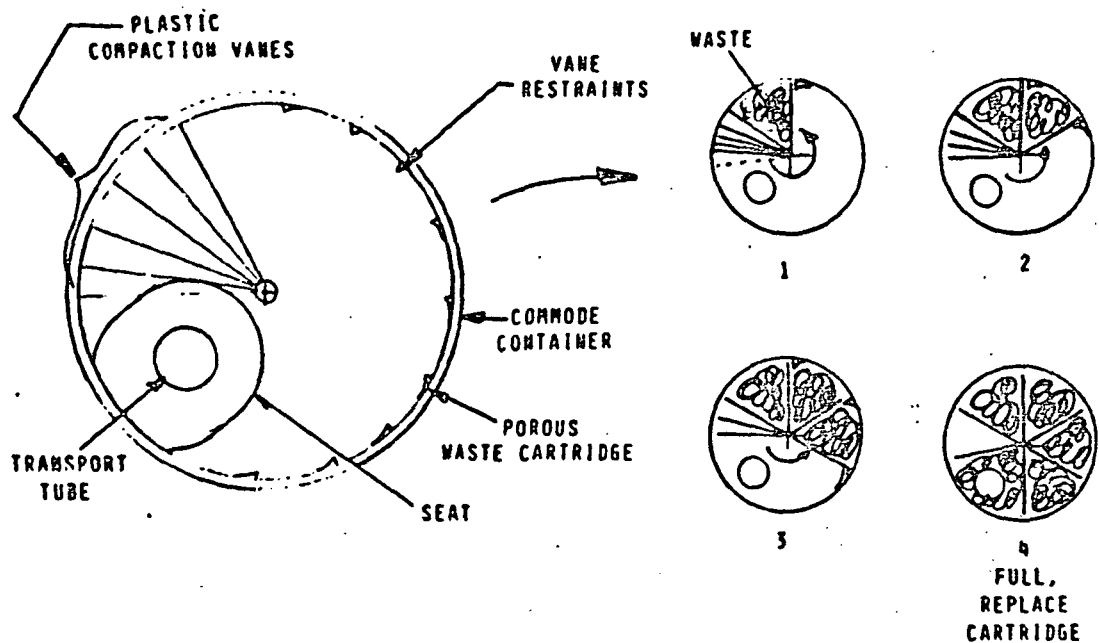
- MECHANICAL COMPRESSION OF FILTER BAG
- VANE COMPACTION
- SLURRY GRINDER
- INCINERATOR
- PLATEN TRANSFER AND COMPACTION

**FIGURE B-1
UNCOMPETITIVE COMPACTION CONCEPTS**



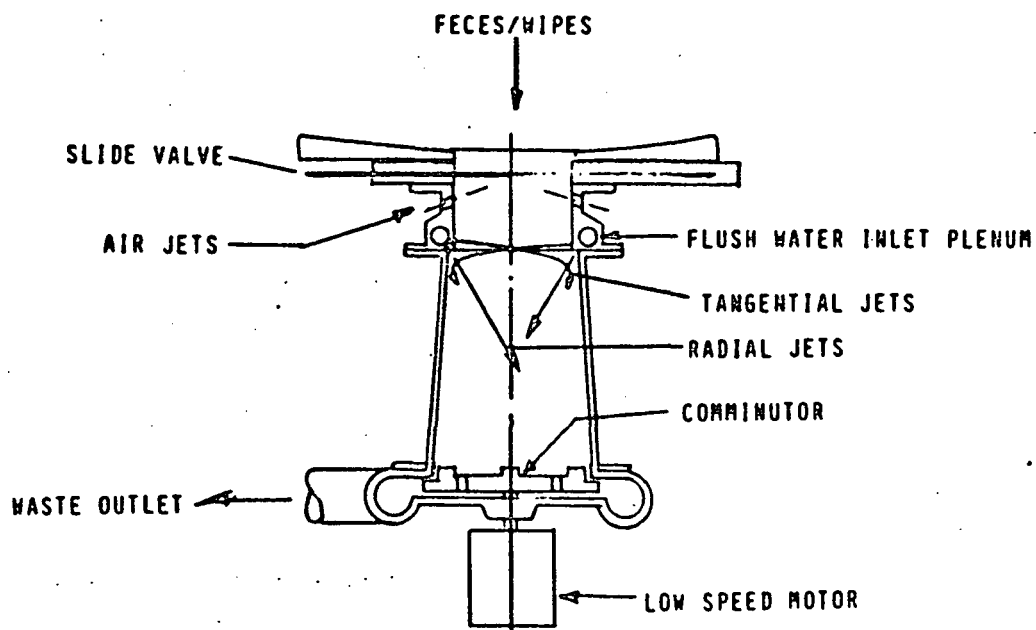
**APPROACH: INSERT WASTES IN CONTAINER & COMPACT.
MECHANISM REMAINS CLEAN.**

**FIGURE B-2
MECHANICAL COMPRESSION OF FILTER BAG**



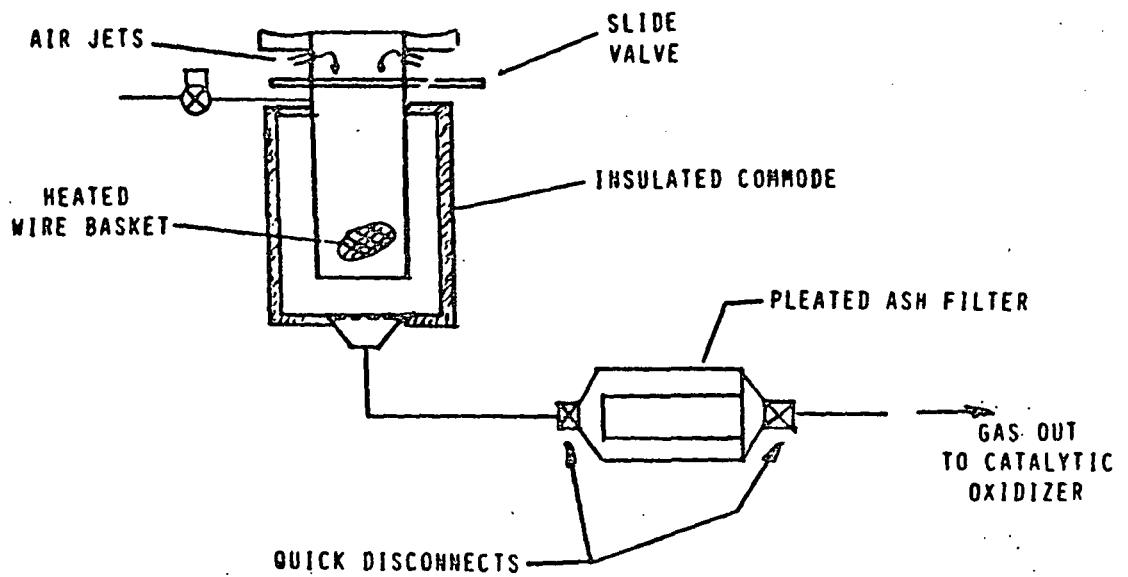
APPROACH: WASTE COMPACTION INSIDE CONTAINER.
COMPACTION DEVICE REQUIRES EXPENDABLE
COVER FOR CLEANLINESS.

FIGURE B-3
VANE COMPACTION



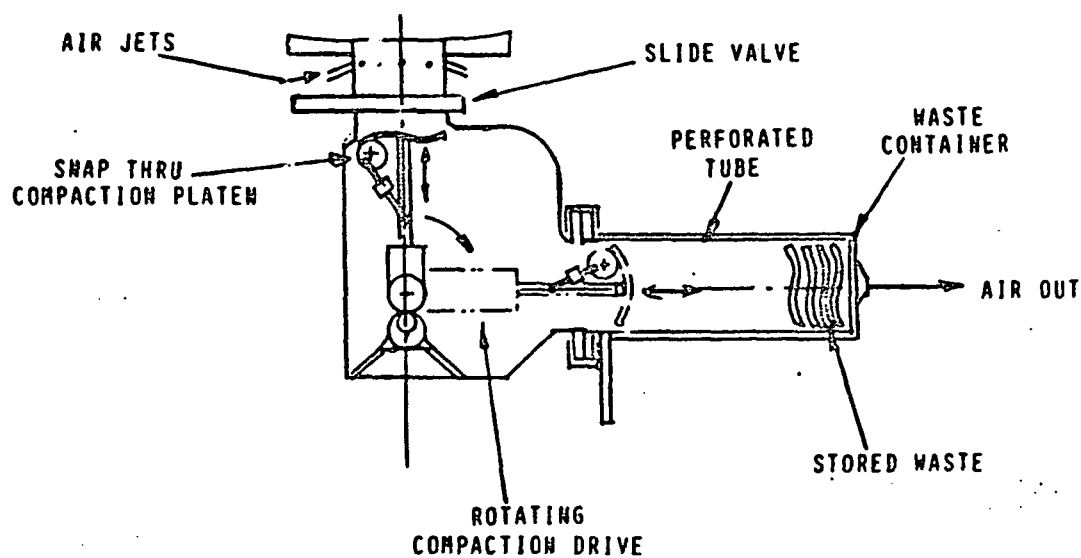
APPROACH: FORM SLURRY AND PUMP TO TANK

FIGURE B-4
SLURRY GRINDER



APPROACH: PROCESS WASTE TO POWDER FORM,
VACUUM TO COLLECTION BAG

**FIGURE B-5
INCINERATOR**



APPROACH: COMPACT WASTE AND CLEAN COMPACTION MECHANISM

FIGURE B-6
PLATON TRANSFER AND COMPACTION



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APPENDIX C

UNCOMPETITIVE TREATMENT CONCEPTS



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APPENDIX C

In this appendix seven concepts are illustrated that were considered as treatment means and were rejected. They are listed in Figure C1 and depicted in Figures C2-C8. A tradeoff tabulation of rejected waste treatment concepts appears in Figure C9. None of these reached the level of feasibility of the concepts described in the main body of the report.

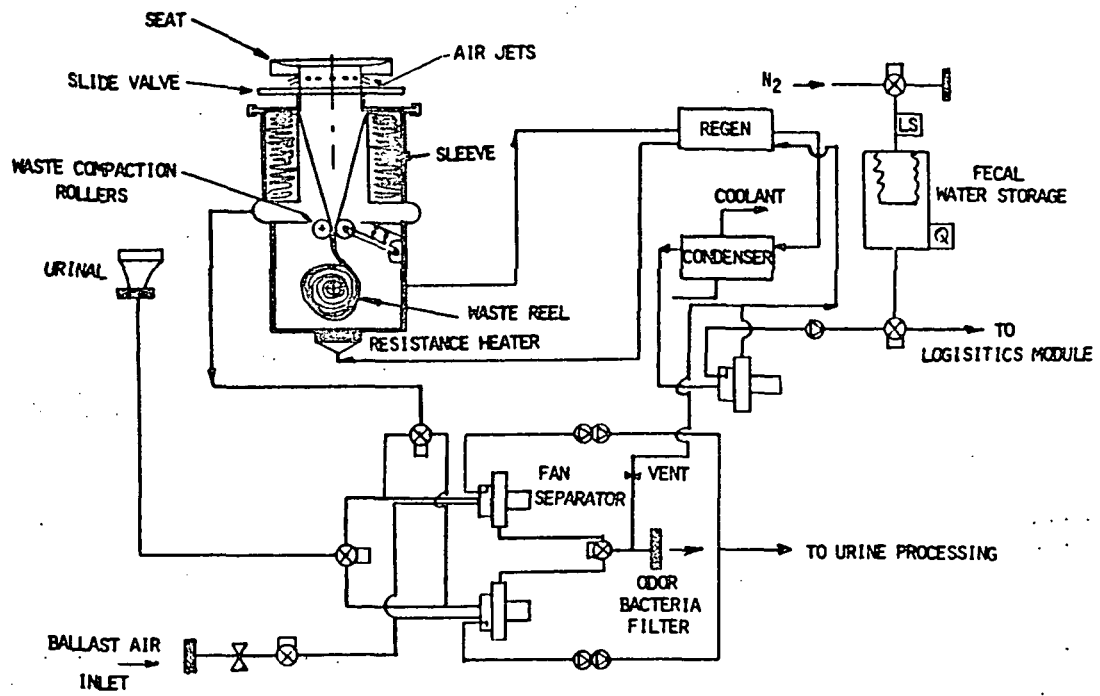


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- HOT AIR DRYING
- MICROWAVE DRYING AT REDUCED PRESSURE
- VAPOR COMPRESSION REFRIGERATION
- AIR CYCLE REFRIGERATION
- BIOCIDES SLURRY STERILIZATION
- INCINERATOR STERILIZATION
- X-RAY STERILIZATION

FIGURE C-1
UNCOMPETITIVE TREATMENT CONCEPTS



**FIGURE C-2
HOT AIR DRYING**

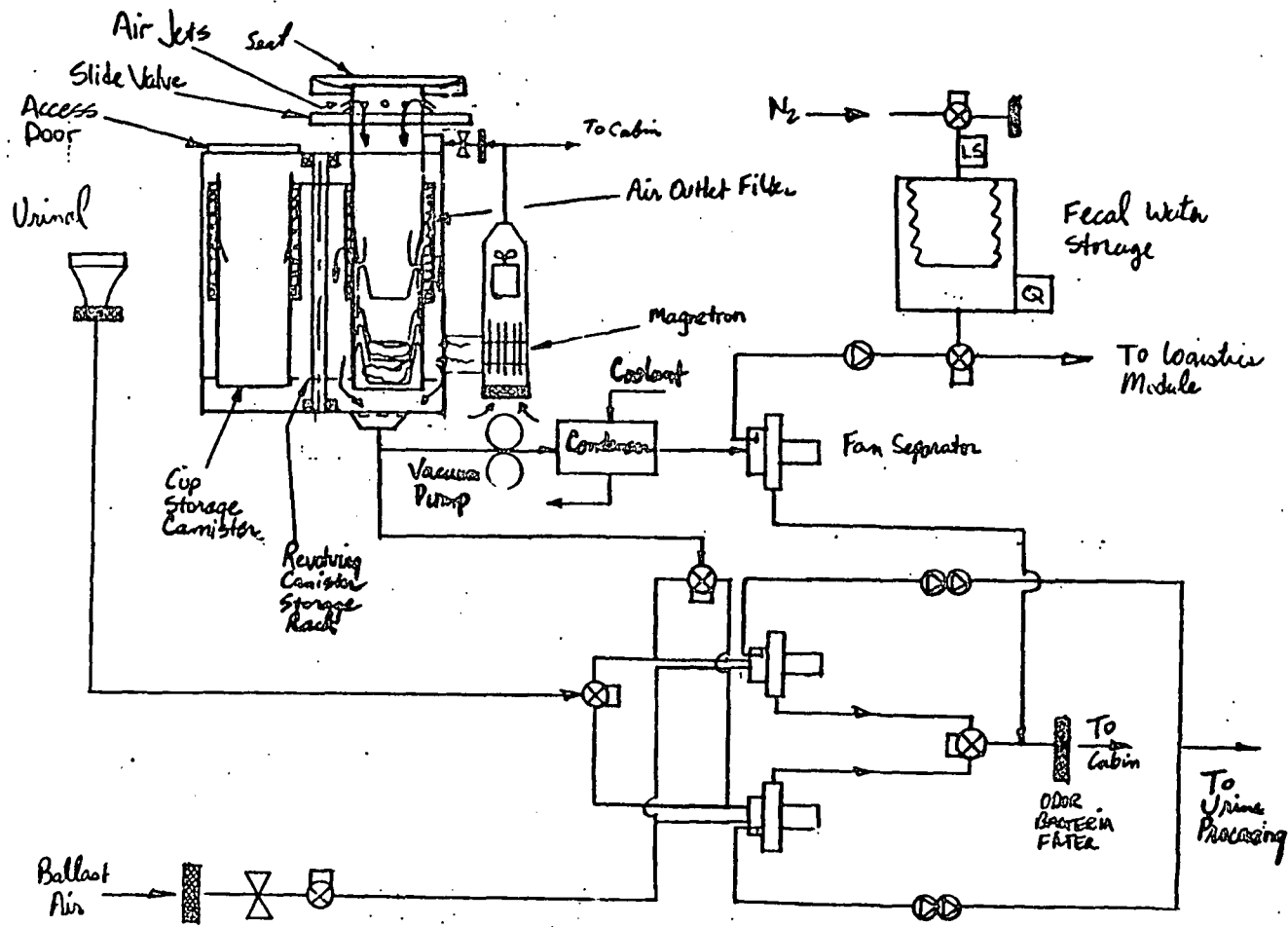
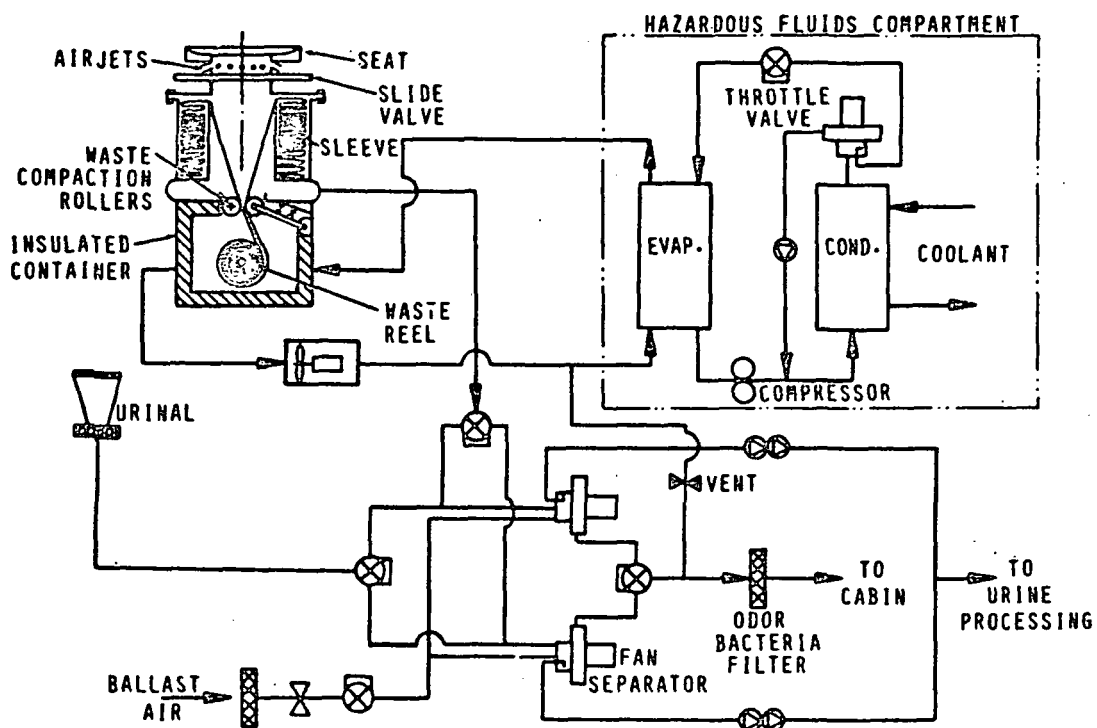


FIGURE C-3
MICROWAVE DRYING AT REDUCED PRESSURE



**FIGURE C-4
VAPOR COMPRESSION REFRIGERATION**



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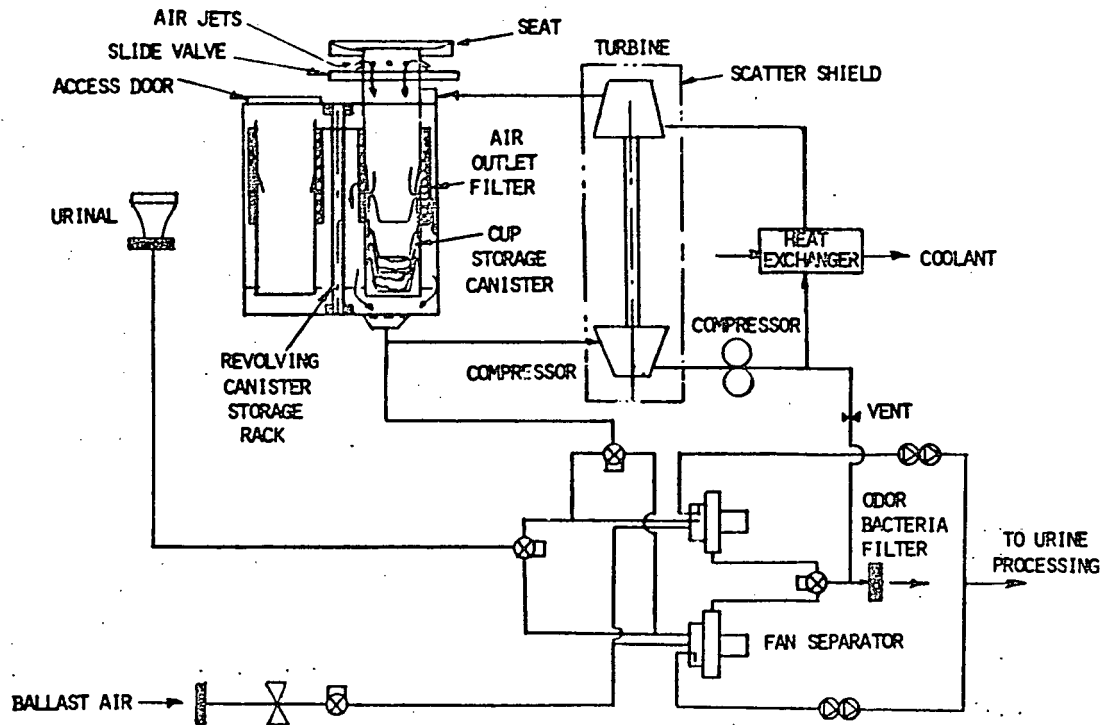


FIGURE C-5
AIR CYCLE REFRIGERATION

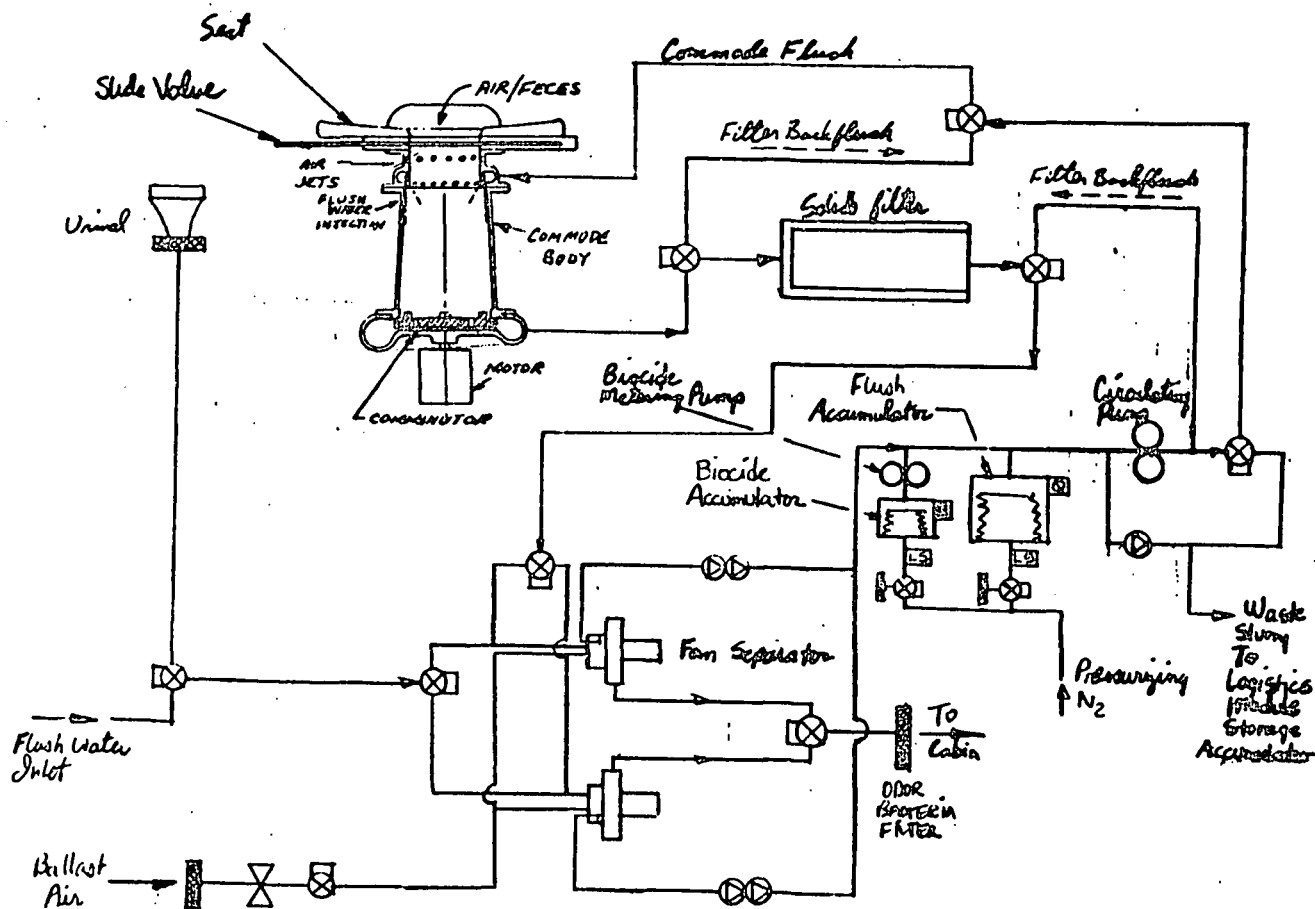


FIGURE C-6
BIOCIDES SLURRY STERILIZATION

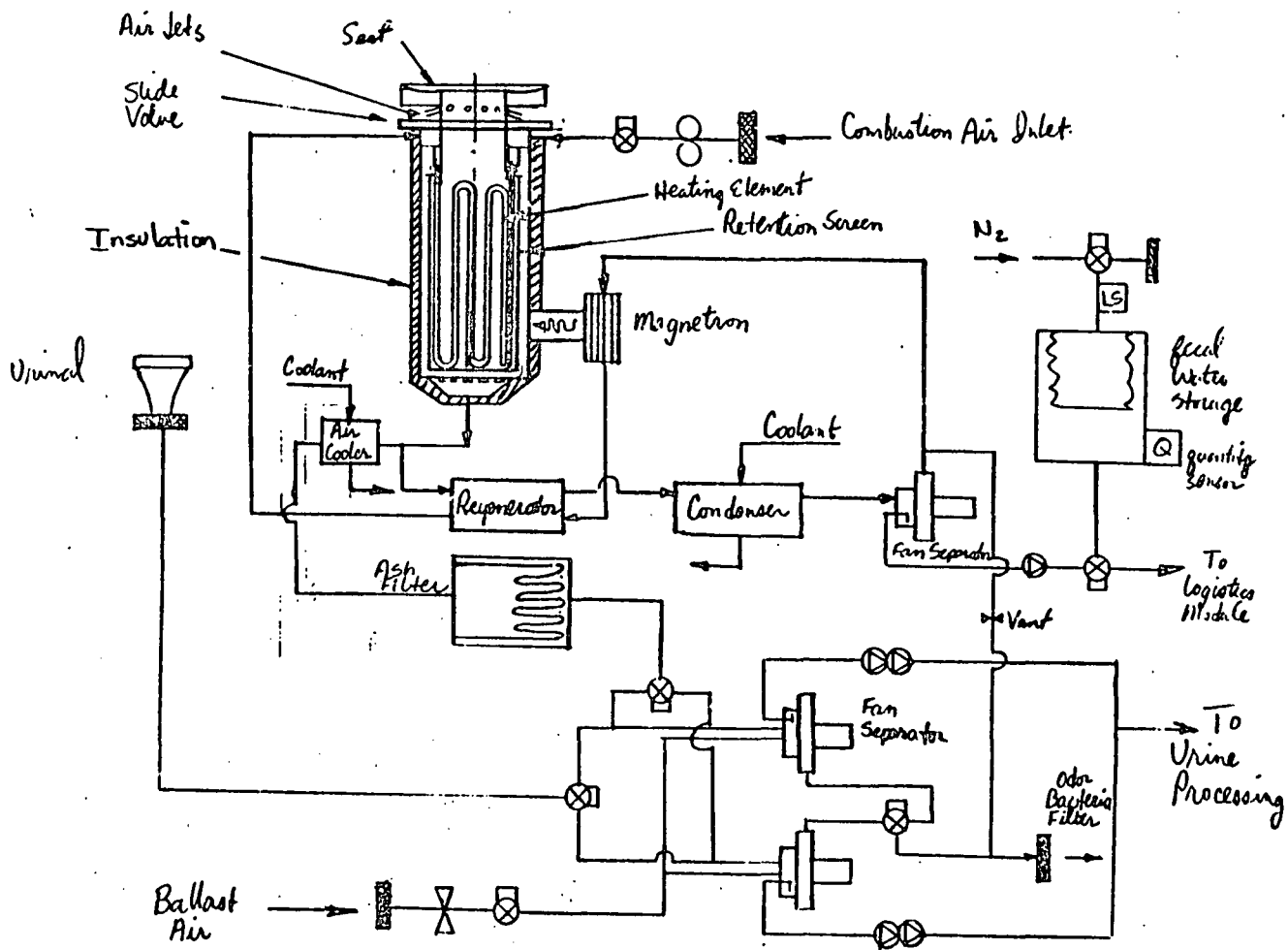


FIGURE C-7
INCINERATION STERILIZATION

ORIGINAL PART
OF POOR QUALITY

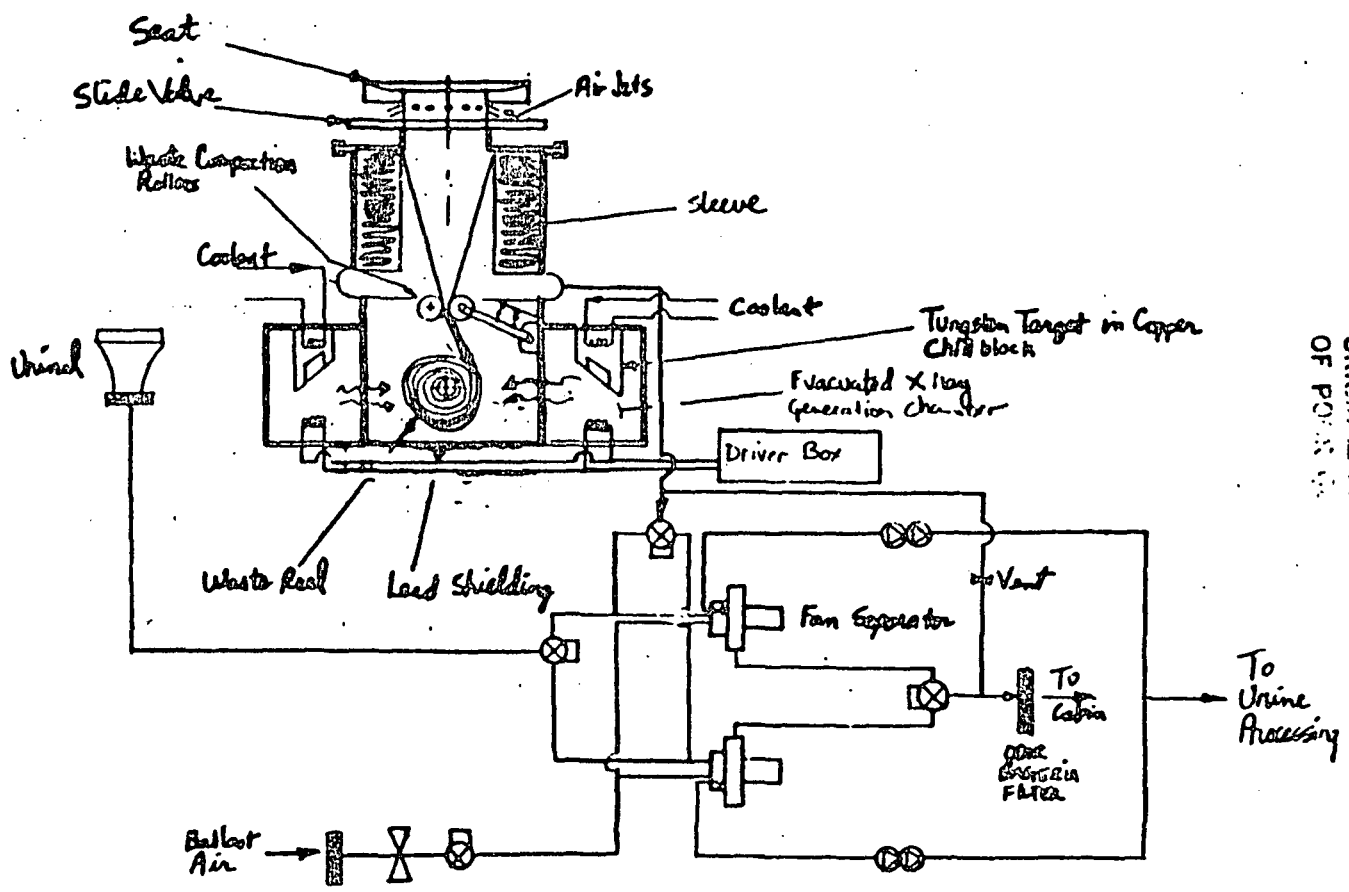


FIGURE C-8
X-RAY STERILIZATION

CODE
5 EXCELLENT
4 VERY GOOD
3 GOOD
2 FAIR
1 POOR

CONCEPT	DRYING				REFRIGERATION						STERILIZATION		
	HOT AIR		REJECTED WASTE		VAPOR COMPRESSION			AIR CYCLE			BIO- CIDE	WARM TREATMENT	X- RAY
	SLV	BAG	CUP	SLV	BAG	CUP	SLV	BAG	CUP	SLV			
<u>ABSOLUTE</u>													
SATISFACTORY	5	5	5	5	5	5	5	5	5	5	5	5	5
UNSATISFACTORY	5	5	5	5	5	5	5	5	5	5	5	5	5
<u>PRIMARY</u>													
CREW ACCEPTABILITY	5	4	5	5	4	5	5	4	5	5	4	3	3
PAPER DISPOSAL	5	5	5	5	5	5	5	5	5	5	5	5	5
NOISE	3	3	3	3	3	3	3	1	1	1	3	4	4
CONTAMINATION	4	4	4	4	4	4	4	4	4	4	3	3	3
RELIABILITY	3	4	3	3	5	4	4	3	2	2	3	3	3
SCORE	20	20	20	20	20	20	20	17	17	17	18	18	18
<u>SECONDARY</u>													
RETROFITABILITY	2	3	2	2	3	2	2	3	2	2	3	3	1
GROWTH POTENTIAL	5	5	5	5	5	5	5	5	5	5	2	5	5
POWER	4	1	1	1	4	4	4	3	3	3	3	1	1
VOLUME	3	3	2	3	3	2	3	3	2	3	3	4	2
WEIGHT	3	3	2	3	3	2	3	3	2	3	2	3	1
COST	4	2	2	2	3	3	3	2	2	2	2	2	2
SERVICING	2	4	3	2	4	3	2	4	3	2	5	5	2
EASE OF OPERATION	4	5	4	4	5	4	4	5	4	4	5	5	4
SCORE	27	26	21	22	30	25	26	28	23	24	25	28	18

FIGURE C-9
TRADEOFF - REJECTED WASTE TREATMENT CONCEPTS